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ABSTRACT

Human resources data (HRD) inputs often fail to influence system development. This study investigated the possibility that these inputs are sometimes deficient in quantity or timing. In addition, the effect upon design of different personnel quality and quantity requirements was analyzed. Equipment and HRD inputs which were produced during actual missile development were presented to eight design engineers, who were required to develop a conceptual design of the equipment. By varying personnel constraints and timing of inputs, the study found that the type of manpower requirement and the amount and timing of HRD inputs influence design, although somewhat unpredictably. The estimates of personnel required to operate and maintain systems does not always relate to design concepts. The study concluded that personnel requirements should be included in proposal requests and work statements and recommended that further research be undertaken to describe the design implications of HRD inputs. (BH)

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THE EFFECT OF AMOUNT AND TIMING OF HUMAN RESOURCES DATA ON SUBSYSTEM DESIGN

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FOREWORD

This study was initiated by the Training Research Division, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, Ohio, under Project 1710, "Human Factors in the Design of Training Systems," Task 1710-06, "Personnel, Training and Manning Factors in the Conception and Design of Aerospace Systems." The research was accomplished by the Human Factors Department, The Bunker-Ramo Corporation, Canoga Park, California under Contract No. F33615-68-C-1367. Dr. David Meister was principal investigator assisted by Mr. Dennis J. Sullivan and Mrs. Dorothy L. Finley. Dr. William B. Askren, HRTR, was the investigator for the Air Force Human Resources Laboratory. The research sponsored by this contract was started on 1 April 1968 and was completed on 31 March 1969. This report was submitted by the authors 30 June 1969.

The authors wish to acknowledge the support and encouragement of M. T. Snyder, Chief, Personnel and Training Research Branch, and Dr. G. A. Eckstrand, Chief, Training Research Division, Air Force Human Resources Laboratory. The assistance of the AGM-69A system project office and Dr. Robert Walker, The Boeing Company, was invaluable.

This technical report has been reviewed and is approved.

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ABSTRACT

The study described in this report had two main purposes: (1) to determine whether the amount and timing of human resources data (HRD) influence design differentially; (2) to investigate the effect upon design of differences in personnel quantity and quality requirements. Equipment and HRD inputs (eg, manning quantity and quality, task and time line analyses, etc.) which were produced during the development of the maintenance equipment of the AGM-69A missile were adapted and presented to eight design engineers during four 4-hour sessions. Subjects were required to develop a conceptual design of the equipment. The experimental design contrasted the simultaneous presentation of all HRD inputs and stringent personnel quantity and quality constraints at the start of design with the same inputs presented incrementally throughout design and "minimal" personnel constraints. Measures of experimental differences included: frequency with which engineers selected an automatic, semi-automatic or manual design solution; number of manual design features included in design outputs; number of test sets; and manpower required by subjects to exercise their systems. It was found that the amount and timing of HRD inputs do exercise some influence on the engineer's design. The personnel requirements imposed did affect design decisions. The type of manpower requirement imposed (skill level versus personnel number constraints) also appeared to make some difference to subjects. Although HRD inputs are responded to by engineers primarily when those inputs are phrased as design requirements, informational inputs (eg, task and time-line analyses) appeared to create an attitude of awareness in engineers of personnel requirements. Skill is considered by engineers to be of greater significance to system performance than numbers of personnel. Engineers display considerable variability in their designs; they develop their design concepts quickly and resist attempts to modify these concepts. They prefer to receive their HRD inputs as early in design as possible. Engineers can and do estimate the manning needed to exercise their equipment, but these estimates do not always seem to relate to their design concepts. The results of the study indicate that, if human resources data are to be incorporated in design, these must be supplied at the start of design and they must be phrased as design requirements.

It is recommended that at the very least the Request for Proposal and the Statement of Work include

(1) Maximum number of operating/maintenance personnel allowed **by job position;**

(2) Maximum skill level allotted for each job position.

SUMMARY AND CONCLUSIONS

PROBLEM

Human resources data (HRD) inputs supplied during design often fail to exercise a significant effect upon that development. It is possible that inputs are both insufficient and presented at incorrect times during development. The study described in this report had two main purposes: (1) to determine whether the amount and timing of HRD influence design; and (2) to investigate the effect upon design of different personnel quantity and quality requirements.

APPROACH

Equipment and HRD inputs which were produced during the development of the maintenance equipment of the AGM-69A missile were adapted and presented to eight design engineers during four 4-hour sessions. Subjects were required to develop a conceptual design of the equipment. The experimental study contrasted: (1) the simultaneous presentation of all HRD inputs at the start of design with the same inputs presented incrementally throughout design; and (2) the effect of personnel quantity constraint versus the effect of personnel skill constraint.

RESULTS

A substantial difference in design outputs was found between the experimental conditions. The group receiving all HRD inputs in the Statement of Work designed significantly more automatic systems, included more manual features in their designs, and required more and higher skilled personnel than the group receiving human resources data inputs incrementally. The apparent inconsistency between more automatic systems and more manual features is explained as partly a problem of defining the nature of automatic systems, since each engineer categorized his own design, and partly, that putting all HRD in the Statement of Work made the designers more personnel conscious and more concerned with designing work into the system for the personnel. The skill-restricted design group required fewer and less highly skilled personnel, more semiautomatic systems, and more test sets than the quantity-restricted design group.

CONCLUSIONS

The amount and timing of human resources data inputs and the type of HRD constraints do influence the engineer's design, but not always in a predictable manner. The fact that a personnel requirement is imposed on engineers does not necessarily mean that they will design to the letter of the constraint. However, it does mean that they will take the personnel factor into greater account than they would if no personnel requirement

had been imposed at all. From this standpoint, the more human resources data provided to the designer, the more conscious he will be of the need to consider personnel limitations in his design, hence the more his design will be affected.

OPERATIONAL IMPLICATIONS

It is recommended that Requests for Proposal and Statements of Work for new systems include

(1) Maximum number of operating/maintenance personnel to be allowed in the crew by job position;
(2) Maximum skill level allowed for each job position;
(3) The task capabilities of these personnel;
(4) The design implications of these requirements in terms of system characteristics.

RESEARCH IMPLICATIONS

Additional research is needed regarding a number of problems. (1) Methods are needed for determining early during the conceptual phase of a system the "likely" manpower force to be available during the time period when the system would become operational. This "likely" force would be derived from sources such as phased out systems, career personnel, new enlistees, and current training courses. (2) Techniques are needed for comparing the "likely" force with alternate forces of varying quantities and skill distributions and determining their impact on the cost, capability, reliability, availability, etc. of the system. Ultimately a "desired" manpower structure would be proposed for the system. (3) The design implications of manpower requirements need to be fully developed, so that the design concepts and characteristics which will yield the "desired" manpower force can be specified in the contract statement of work. For this research to have maximum validity, it should study the performance of personnel at operational sites in relation to the design concepts of the system. (4) Finally, methods are needed for periodically testing during design and development for compliance of design with the manpower requirement constraints.

CONTENTS

I. INTRODUCTION 1

A. Nature of the Problem 1

B. Purpose of the Study 4

II. TEST METHODOLOGY 7

A. General Strategy 7

B. Development of the Experimental Situation 8

C. Experimental Design 23

III. RESULTS AND CONCLUSIONS 34

A. Introduction 34

B. Summary of Results 36

C. Detailed Results 39

IV. RECOMMENDATIONS 62

Appendix I: Abbreviated Scenario of Equipment and Personnel Inputs Provided to Engineer-Subjects 64

Appendix II: Typical Design Outputs 119

Appendix III: Applications to the Design Process of the Queuing Technique for Determining System Manning Requirements 126

References 132

LIST OF ILLUSTRATIONS

Figure 1 Human Resources-Design Relationships 3

Figure 2 First Level Functions: Flight Line Maintenance 89

Figure 3 Second Level Functions: Flight Line Maintenance 90

Figure 4 Third Level Functions: Flight Line Maintenance 91

Figure 5. Personnel Function Flow Diagrams: Flight Line Maintenance 92

Figure 6 First and Second Level Functions: Shop Maintenance 93

Figure 7 Third Level Functions: Shop Maintenance 94

Figure 8 Personnel Function Flow: Shop Maintenance 95

Figure 9 Time Line Analysis: Flight Line Maintenance 96

Figure 10 Time Line Analysis: Shop Maintenance 97

Figure 11 Task Analysis 98

Figure 12 Requirements Allocation Sheet 102

Figure 13 Tradeoff Decision-Making Matrix 120

Figure 14 System Description 121

Figure 15 Flow Diagram of System Inputs and Outputs 122

Figure 16 Equipment Operating Procedure 123

8

LIST OF TABLES

Table I.	Subject Education and Experience	11
Table II.	List and Definition of Human Resources Data Inputs	14
Table III.	Statement of Work Contents	16
Table IV.	Sequence of Test Inputs and Outputs for Design of the Experimental Subsystem	18
Table V.	Experimental Design for Study	32
Table VI.	Summary Table of Results	34
Table VII.	The Effect of Amount and Timing of Human Resources Data Inputs on Design	39
Table VIII.	Summary of Design Solutions	41
Table IX.	Summary of Manual Design Features	46
Table X.	Subjects Estimates of Manpower Required (Flight Line and Shop)	47
Table XI.	Human Factor Specialists Analysis of Differences in Manpower Required by Subject Designs	49
Table XII.	Design Changes Resulting from Addition of MR Constraints	52
Table XIII.	Preference for HRD Inputs at System Development Stages	54
Table XIV.	Manpower Estimated by Subjects for Experimental Subsystems	57
Table XV.	Distribution of Estimated Manpower by Group, Maintenance Area and Subsystem Type	59
Table XVI.	Comparison of the Design Engineers Estimate of Subsystem Manpower with Human Factor Analysis of Subsystem Manpower Requirements	60
Table XVII.	Environmental Conditions	80
Table XVIII.	Alternative System Configurations	108

SECTION I

INTRODUCTION

A. NATURE OF THE PROBLEM

Although it is a commonplace that human error contributes significantly to system breakdown or mission failure, it is equally well known that human resources data (HRD) supplied during system development (ie, those describing the quantity, type and functions of manpower needed to operate and maintain an equipment effectively) often fail to exercise a significant effect on that development.

The fact that engineers characteristically do not take human factors inputs into consideration during equipment design has been documented in a series of studies (Meister and Farr, 1966, Meister and Sullivan, 1967, Meister, Sullivan and Askren, 1968, and Snyder and Askren, 1968). It is also reported anecdotally by many human factors specialists working on development projects.

Why does this condition exist? There are several possible explanations. If the engineer does not make use of certain inputs, it may be that these inputs do not contain the information he needs to make design decisions; or the inputs may be late in reaching him and hence cannot influence an already completed design; or else these inputs may be formulated in terms which the engineer cannot understand and utilize. Underlying these hypotheses is the assumption that, given the engineer's eagerness to scrutinize as much information bearing on design as possible (a fact which was demonstrated in Meister et al., 1968), an input which fails to influence design fails to do so because it lacks some characteristic required by the engineer.

To study this problem it is necessary to investigate the conditions under which HRD can and will be utilized by the engineer. The following factors must be examined:

(1) The manner in which the engineer designs, because human resources inputs must fit into that process;

(2) The format or manner in which these inputs are supplied to design engineers;

(3) The timing or sequence with which inputs are supplied;

(4) The design-relevancy of the data supplied;

(5) The effect of manpower requirements as constraints on hardware design;

(6) The availability of information as a whole to the engineer during the design process;

(7) The engineer's attitude toward the personnel aspects of the system and to human resources data as inputs to design.

To study these factors human resources inputs must be presented to engineers in different formats under controlled conditions in a realistic design context. The designs they produce as a consequence of different experimental treatments can then be related to the factors described in these treatments.

Before considering the purpose of the present study it is necessary to describe the authors' concept of Human Resources Data (HRD). This has been expressed graphically in Figure 1. There are two types of HRD: (1) Manpower Requirements (MR), which specify the maximum number and skill levels of personnel for whom the system is to be designed; (2) Support Data (SD), eg, Quantitative and Qualitative Personnel Requirements Information (QQPRI), personnel availability, task and time line analyses and training analyses. MR have -or should have- a direct influence on the engineer by requiring him to modify his design to meet the manpower requirements. SD are the backup analyses which lead to the development of MR, and which also serve as descriptive data explaining the implications of MR to the engineer.

Note that SD do not directly influence design; that function is reserved to MR. SD may, however, give rise to Support Requirements when its analyses are transformed into descriptions of tasks for which the system must be designed and the training which system personnel must receive.

It should be noted that the effect of both MR and support requirements on design must be mediated by the determination of the human resources-hardware relationships (design implications) of these requirements. When such implications are not explicitly developed and provided as guidelines to the engineer, the effect of MR and support requirements (particularly the latter) is largely nullified. In another study (Meister et al., 1969) it has been pointed out that the data describing these design implications is largely lacking, which accounts for the relatively weak influence quality manpower requirements and personnel support data have had on previous design.

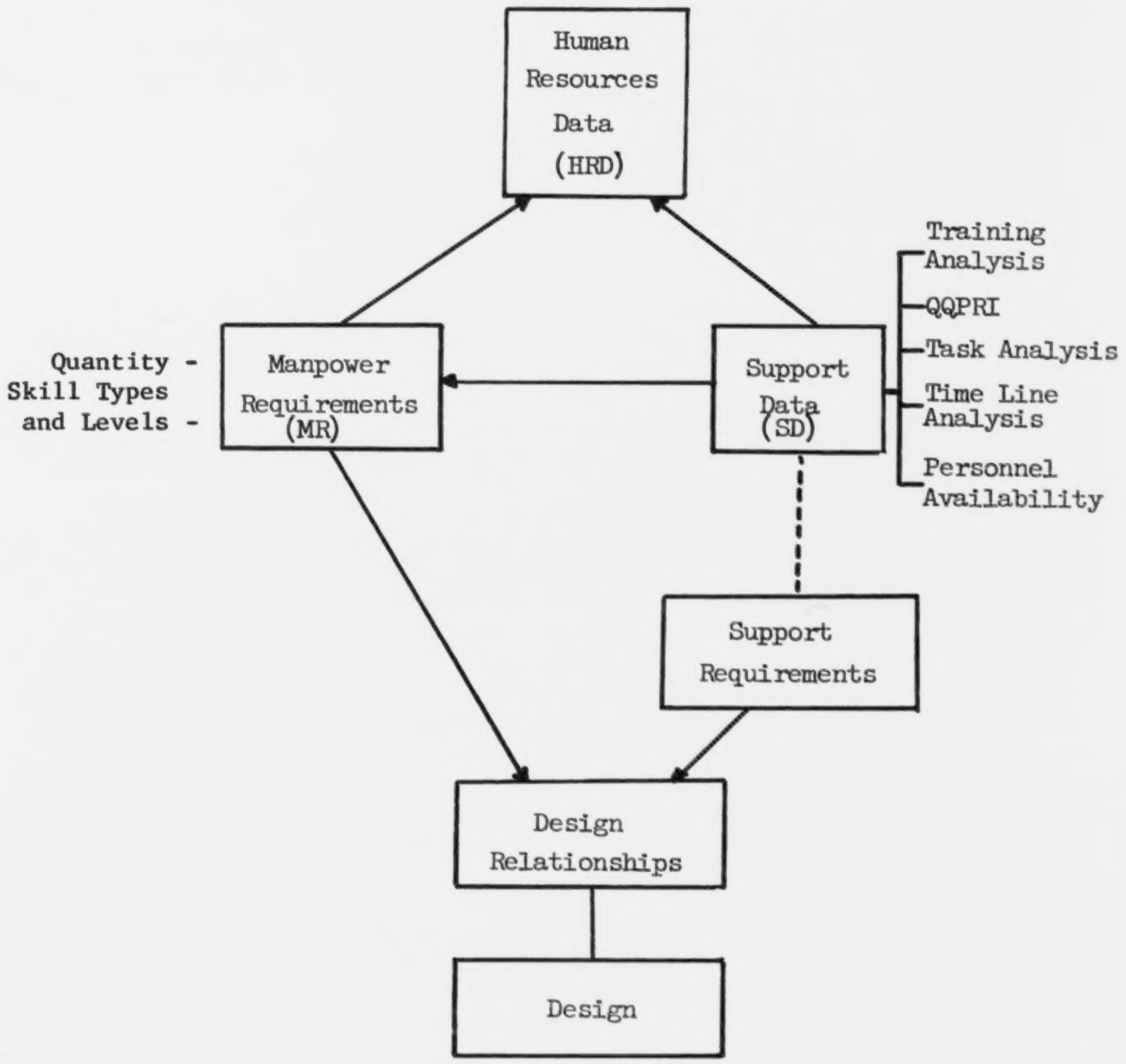

Figure 1. Human Resources - Design Relationships

B. PURPOSE OF THE STUDY

This study had two major purposes: (1) To test the hypothesis that the quantity and timing of HRD provided to design engineers will influence the nature of their designs; and (2) to investigate the effect upon design of differences in MR (manpower quantity and quality requirements).

The present study is in large part a replication of a previous one (Meister et al., 1968) to verify trends uncovered in the earlier study. That study sought to determine the effect on system design of using MR and SD as design inputs.

In that study equipment data and personnel inputs, eg, quantity and skill level of manning, and task information, were presented incrementally to six design engineers in a simulation of the Phase 1A/1B development of the Titan III propellant transfer and pressurization subsystem. Subjects were required to create a complete subsystem design, including schematics, equipment descriptions, drawings and bills of material.

It was found that MR and SD do influence the equipment configuration, but only moderately, because equipment design proceeds so rapidly that HRD inputs presented incrementally inevitably lag design. Engineers were found to be responsive only to inputs which are framed as design requirements. Although MR inputs in terms of quantity (ie, number of personnel) were readily grasped by engineers, they experienced great difficulty in understanding and utilizing quality, ie, skill level, inputs. The results of the study indicated that if personnel factors are to be incorporated into design, HRD inputs must be supplied as design requirements to the engineer in the statement of work (SOW) preceding design. On the basis of that study the following hypotheses seemed in order.

(1) Design engineers approach their problems from the start with preconceived concepts and very rapidly organize their subsystem designs in equipment terms. They proceed very quickly through such initial system analytic stages as determination of subsystem functions, allocation of functions between equipment and personnel, and determination of equipment types and functional characteristics. This approach appears to be characteristic of all types of engineers, even those who are highly sophisticated in system analysis. The stages so compressed are those to which HRD should contribute, if HRD is to have a significant impact on the basic nature of subsystem design.

(2) Because of the manner in which he designs, the primary source of the engineer's design decisions appears to be the SOW with which he begins design. His design is primarily affected by the requirements and constraints expressed in the SOW.

(3) HRD inputs are utilized if they can be interpreted by the engineer in terms of requirements or constraints, or if they provide information about the subsystem which implies requirements or constraints. This means that, as was pointed out earlier, the design implications of MR and SD must be made explicit by the human resources specialist in such a way that the engineer readily recognizes them.

The implications of these hypotheses suggest that HRD inputs will be maximally effective if they can be presented to the engineer as design requirements or constraints within the SOW. This is in line with the concepts expressed by Eckstrand et al. (1968) in their paper on the changing philosophy of human resources engineering. Because the design engineer so rapidly translates system requirements into hardware equivalents, HRD inputs will be effective only to the extent that they exercise the control Eckstrand et. al. recognize as the next stage in human resources engineering. Where HRD inputs are ineffective, it is probably because these inputs fail to exercise as much control as do equipment inputs.

There appears to be some evidence also that design engineers, in developing their basic subsystem concepts, have some general ideas of the crew which they believe will operate and maintain the subsystem. It would be extremely helpful, in defining HRD parameters more precisely in the SOW, to investigate in greater detail the nature of the crew concept which the engineer utilizes as the basis for his design. This would enable investigators to redefine MR in terms which the designer will more readily recognize as being design-relevant.

If the conclusions of that study are valid, then presentation of more comprehensive HRD inputs to the engineer in the SOW, including rigorous MR requirements, should lead to major differences in resultant designs.

The goals of the study described in this report can therefore be phrased as a series of questions to be answered:

(1) Will differences in amount and timing of HRD inputs result in different design concepts?

(2) Will quantity (ie, number of personnel) constraints produce different effects on design than quality (ie, skill level) constraints?

(3) Will the *imposition* of MR constraints affect equipment characteristics *after* the basic design concept has been developed?

(4) Will the *removal* of MR constraints affect equipment characteristics *after* the basic design concept has been developed?

(5) Which HRD inputs are preferred and utilized by engineers and at what stage in system development?

(6) How does the engineer's concept of manpower for his system relate to his design and how does this concept relate to more objective methods of predicting manpower (eg, Barton et al.'s, 1964 queuing model)?

The ultimate purpose of the present study is to derive from the controlled testing of engineers certain human resources-hardware relationships which would enable the Air Force to write more effective procurement requirements. It is assumed that if, instead of general, non-enforceable manpower provisions, explicit design-relevant statements of human resource needs can be incorporated in procurement requirements, more satisfactory equipment will be developed.

SECTION II

TEST METHODOLOGY

A. GENERAL STRATEGY

The methodology employed in this study has been described in detail in Meister et al., 1968. Hence only that information needed by the reader who is unfamiliar with the preceding study will be presented in this section.

The overall research strategy involves placing the engineer in a realistic design situation in which he must solve a series of design problems by using equipment and HRD information related to these problems. In adapting this general methodology to the present study, the following steps were performed:

(1) Selection of an already existent subsystem which could serve as a model for the development of test inputs and outputs.

(2) Selection of appropriate engineer-subjects skilled in design of the type of subsystem selected.

(3) Determination of the equipment and HRD inputs which are characteristically provided during the system definition phase of development.

(4) Development of HRD inputs.

(5) Determination of the sequence in which HRD inputs should be provided.

(6) Determination of the design responses and outputs which the engineer-subjects should apply in attempting to solve the design problems.

(7) Determination of specific measures which could be used to answer the questions which initiated the study.

B. DEVELOPMENT OF THE EXPERIMENTAL SITUATION

1. Selection of the Test Subsystem

A. Rationale

The initial step in the development of the experimental situation was the selection of a subsystem which already existed, if not in hardware form, then in the form of a completed design. This subsystem could then be used as a model to develop the necessary study inputs and outputs.

The idea of using an already existent subsystem as a model for test inputs has been found to be useful, for several reasons:

(1) Both equipment and HRD inputs, the details of which would otherwise be difficult to create if one had to create them out of imagination, could be abstracted from the original documentation.

(2) The amount of informational detail that should be provided at the various stages of the experimental subsystem development could be determined from the original documentation.

(3) The face validity (i.e., realism) of the inputs could be assured because they were produced in the original subsystem design.

(4) The design responses required of subjects could be determined on the basis of the design outputs developed in the original subsystem.

B. Criteria for Selecting the Model Subsystem

The criteria for selection of the model subsystem were as follows:

(1) The subsystem should be one in which personnel functioning is important. For this reason it was decided to select a maintenance subsystem. Since many operator subsystems in present Air Force systems are highly automated, it was considered that a maintenance subsystem would offer a greater amount of direct personnel-equipment interaction.

(2) The subsystem should have an appropriate degree of complexity. Overly simple subsystems were avoided since the number of HRD inputs and their effect on subsystem design would be minimal. At the same time an overly complex subsystem would make it difficult to supply the necessary design inputs within the time schedule established.

(3) The subsystem should be one whose development proceeded in accordance with AFSCM 375-5 (USAF, 1964). AFSCM 375-5 was utilized as a framework for the development of the experimental HRD inputs because Air Force systems are presently required to be developed in the spirit, if not to the letter, of AFSCM 375-5.

(4) The unclassified records of the model subsystem should be complete enough to minimize the development of new material (as opposed to the editing or revision of old material).

(5) The subsystem should be recently included in the Air Force inventory, or under development, so that the inputs would take advantage of recent technical developments in the state of the art.

C. The Subsystem Selected

With these criteria in mind, several alternative subsystems were considered and evaluated before the investigators selected the model subsystem.

The subsystem selected for simulation was the unclassified aspects of the Aerospace Ground Equipment (AGE) of the AGM-69A, the SRAM. The AGM-69A is an air to ground missile designed to be launched from the B-52 bomber. It is presently under development by the Boeing Company, Seattle, Washington.

The specific equipment to be designed by the engineer subjects was the electronic test equipment used to check out the status of the missile prior to its installation on the aircraft, to troubleshoot the missile if any malfunctions were found in pre-installation checkout, and to check out missile-related aircraft systems. Unclassified details of the required characteristics of the AGM-69A test equipment may be found in Appendix I.

2. Selection of Subjects

The eight engineers who made up the subject population for this study were selected from the test engineering department of the Marquardt Corporation, Van Nuys, California. Engineers were selected from this company because the design of the maintenance equipment for the AGM-69A required the selection of personnel skilled in the design of test equipment used to check out missiles and missile-related equipment.

An analysis of the education and experience background of the subjects is presented in Table I. The subjects are considered to be essentially equivalent in terms of relevant experience to those of the earlier study (Meister et al., 1968). They are also considered on the basis of their verbal responses during the experiment to be similar to the 36 engineers tested earlier in studies described in Meister and Farr, 1966, Meister and Sullivan, 1967 and Meister et al., 1968. The average amount of experience is 15.7 years, with no subject having less than 8. Beyond a certain experience level, represented by the present subject group, differences in years of experience are felt to have little or no significance for design output.

3. Determination of Equipment Inputs

A. Description of Inputs

In addition to HRD inputs, equipment inputs were provided to serve as the context for the HRD inputs as well as the information base for the design. These included the following:

(1) Statement of work which initiated subsystem development.

(2) System and equipment functional flow diagrams (at successive levels of detail).

(3) Requirements Allocation Sheets (RAS).

(4) Descriptions of equipment characteristics.

Few changes were made to the original specification for the AGM-69A test equipment and then only to facilitate its use by subjects. Significant changes were made in the phraseology of section 5.1 (Personnel Manning Requirements) to implement the various experimental treatments in the study. Changes were also

TABLE I

SUBJECT EDUCATION AND EXPERIENCE

Subject	Education	Years of Experience
Y	BSEE	12
L	BSEE	11
F	BS	17
Mc	MSEE	12
M_o	BSEE	8
M_a	BSEE	21
K	BSEE	22
W	BS	23
		15.7

made to the reliability and maintainability sections of the section, since the original specification for the test equipment did not contain subsystem reliability/maintainability requirements. The values supplied were based on those found for similar test equipment in other systems.

To develop the equipment inputs, unclassified documentation produced during the development of the AGM-69A was examined, courtesy of the Boeing Company and AGM-69A System Project Office; pertinent material was extracted and prepared as shown in Appendix I. To ensure technical accuracy and completeness of the equipment inputs provided to the subjects, they were reviewed by the Chief Design Engineer of The Marquardt Corporation, and required revisions were incorporated.

All inputs were provided in complete form except where it was desired that the subject solve a problem which required him to develop or complete some part of the input. For example, if system functions on Requirements Allocation Sheets were to be analyzed by the subject to determine appropriate equipment characteristics, all necessary data were included on the sheets except for those dealing with the equipment characteristics. Complete inputs were provided because the designers were not expected to be able to develop all the documentation which would ordinarily be developed due to the time-scale involved in the simulation. Moreover, all HRD inputs were presented in toto, since designers do not ordinarily develop such inputs and do not have the experience needed to do so.

B. Input Presentation Ground Rules

The following ground rules were followed:

(1) All inputs to subjects were supplied in written form, except where immediate circumstances (e.g., answers to questions asked by the subject during the test session) made this impossible. Any input provided orally was documented immediately following its transmission.

(2) Instructions to subjects were provided verbally, but they were allowed to read the same instructions in written form; and those written instructions were available to him throughout the test session.

4. Development of HRD Inputs

The HRD inputs selected for presentation to subjects were those which are developed as a result of analyses performed during Phases 1A/1B of the System Definition Stage and prior to the Acquisition Phase of System Development. Consequently, whether provided either as part of the SOW or incrementally, they were of a general nature describing system functions rather than those describing molecular human engineering details relevant to hardware components. Previous studies have indicated that the basic design is "frozen" prior to Acquisition; human engineering inputs therefore represent only minor refinements to the Phase 1A/1B design.

According to AFSCM 375-5 human factors inputs should be available prior to the issuance of an RFP to the contractor. From that standpoint it was considered appropriate that for one of the two subject groups these inputs should be included in their SOW before these subjects began their design.

In practice, however, the Air Force often delegates to a contractor the responsibility for developing these inputs after design has begun. When this occurs, HRD inputs are usually provided to the design engineer on an incremental basis. From that standpoint it was considered legitimate to present these inputs to a second group of subjects on an incremental basis.

The HRD inputs provided are listed in Table II and are also presented in Appendix I.

Material supplied in the SOW is listed in Table III.

5. Determination of the Sequence of Providing HRD Inputs

A. Simulation of the Development Process

System development, either as formally defined by AFSCM 375-5 or as actually practiced, is a process of multiple iterations; however, it has been documented (Meister et al., 1968) that the basic design concept is developed very early in the iterative cycle, and that subsequent iterations only serve to refine the basic design concept.

For this reason is was felt that the design simulation could be compressed into four 4-hour sessions without any great loss of precision in the experimental results. For one group of subjects (called the Omnibus group) all MR and PSD inputs were supplied as part of the SOW with which they began

TABLE II

LIST AND DEFINITION OF
HUMAN RESOURCES DATA INPUTS

I. MANPOWER REQUIREMENTS

Item	Definition
(1) Number of personnel	Quantity of personnel required to perform subsystem operations, defined in terms of maximum number allowed.
(2) Skill level	Air Force skill levels allowed for the task.

II. SUPPORT DATA

Item	Definition
(1) Lists of personnel tasks	Tasks defined in terms of personnel functions and equipment acted upon.
(2) Personnel/equipment flow diagrams	Diagrams illustrating the sequencing and interrelationships among tasks.
(3) Personnel/equipment analyses	Description of equipment characteristics required by tasks or effect of equipment characteristics on task performance.
(4) QQPRI Data including:	
(a) Proficiency	Skill characteristics which personnel should possess to perform the job satisfactorily.
(b) Skill type	Characteristics of the job to be performed in terms of demands upon personnel.
(c) Personnel availability	Definitions of AFSC type possessing necessary qualifications to perform the job, together with the probability of such personnel being available for the job.

TABLE II (Continued)

LIST AND DEFINITION OF
HUMAN RESOURCES DATA INPUTS

Item	Definition
(5) Training requirements, including:	
(a) Anticipated training time	Time needed to train to given level of proficiency.
(b) Required aptitude	Job skills which training should provide.
(6) Task analysis, including:	
(a) Task structure	Task description in terms of function and equipment operated or maintained (See Item II (1)).
(b) Task criticality	Consequences of task being performed incorrectly or not at all.
(c) Team performance	Number of personnel required to perform the task.
(d) Probability of successful task completion	Quantitative estimate of probability that the task will be completed successfully by personnel (the converse, error probability, also is provided).
(e) Task location	Approximate physical area (e.g., flight line, shop) in which the task must be performed.
(f) Task duration	Estimate of the time required to perform a task.
(g) Difficulty index	Estimated difficulty of task defined in terms of error probability and response time.
(7) Time-line analysis, including task frequency	Distribution over time, including overlaps, of individual task durations.

TABLE III

STATEMENT OF WORK CONTENTS

* 1. Description of system requirements

* 2. Equipment requirements

* 3. Top level flow diagrams

4. Lists of personnel functions and tasks

5. Maximum number of personnel or skill level requirements

6. Task descriptions (eg, material contained in preliminary and full scale QQPRI)

7. Personnel availability data

8. Task characteristics

9. Time line analysis

10. Position descriptions

11. Preliminary training requirements

The asterisk (*) indicates what was included in the SOW for those subjects receiving HRD inputs incrementally. The remainder of the data were provided to these subjects progressively throughout the study. Other subjects received all SOW contents at the start of the study.

design. For the comparison subjects (called the Incremental group) only a minimal MR requirement was supplied in the SOW and HRD inputs were delayed until the third and fourth sessions. The minimal MR requirement and the delay in HRD inputs were considered characteristic of present practice in system development.

All equipment information was provided to all subjects as part of the SOW.

Table IV presents the sequence of test inputs and outputs for design of the experimental subsystem.

B. Test Procedure

The general procedure for the individual sessions was to determine the effect of a particular input on the design task. At the start of each session, the engineer was told his design task, the inputs available to him were described, and he was asked to review them (in the event he had not reviewed them since he was first handed them at the close of the previous session). The subject then performed his design task.

About a half hour before the end of the session (unless he obviously was not finished, in which case the session would be continued to the following week), the subject was informed that his work was to be reviewed. His output then was reviewed by the investigator with him to elicit any additional information and particularly the reasons why particular design features were incorporated. At the same time, the subject was questioned to determine whether: (1) he thought the input was useful, (2) the input was understandable and meaningful, (3) he used the input in deriving his design product, (4) the format of the input was satisfactory, (5) the timing of the input was appropriate, and (6) any additional information was needed.

At the close of the session he was handed the inputs for the next session and asked to study them if he had sufficient time.

The progressive development of the experimental subsystem was simulated by scheduling each subject individually for a minimum of four weekly three-to-four-hour sessions (the length of the session depending on their speed). For the Incremental group this permitted the progressive inputting of HRD according to the schedule described in Table IV. The subject had available to him at each successive test session all the data

TABLE IV

SEQUENCE OF TEST INPUTS AND OUTPUTS FOR DESIGN OF THE EXPERIMENTAL SUBSYSTEM

Introductory Session

Session 1

Inputs

Omnibus Group: Complete SOW
Incremental Group: Partial SOW
Output Required: Describe how maintenance will be accomplished and provide a detailed flow diagram of ground operations

Session 2

Inputs

Omnibus Group: None
Incremental Group: None
Output Required: Identify elements of AGE required to perform the maintenance needed; provide functional descriptions of what each individual functional equipment is supposed to do.

Session 3

Inputs

Omnibus Group: None
Incremental Group: Third level equipment and personnel flow diagrams.
Output Required: Supply equipment descriptions of individual AGE elements

TABLE IV (Continued)

SEQUENCE OF TEST INPUTS AND OUTPUTS FOR DESIGN OF THE EXPERIMENTAL SUBSYSTEM

Session 4

Inputs

Omnibus Group:	None
Incremental Group:	Task analysis and QQPRI (position descriptions, training requirements and personnel availability statements)
Output Required:	Complete detailed description of maintenance equipment

(and his previous design outputs) from preceding sessions. At each session, the subject was asked to supply certain design outputs which the investigators hypothesized should be affected by the HRD input for that session.

6. Determination of Design Outputs

A. Types of Outputs

The response secured from the subjects fell into two general classes, attitudinal or subjective outputs, and application, or product outputs.

When an HRD input was first presented to a subject he was asked (after he had reviewed the input) to indicate his personal response to the input. By this is meant that the investigators sought to determine how the subject felt about his immediate input; whether he understood it, and if not, why; whether he felt he could use the input, and if not, why, etc. Since the engineer must first be positively motivated to accept an input before he applies it, subjective responses were secured before proceeding to more objective outputs.

After the subject completed his subjective evaluation of the input, he was required to make use of the input by performing some engineering analysis or developing some engineering output, such as a drawing to which the HRD input was related. He was required to make use of the HRD input even though he may have indicated earlier that he could make little use of it. This was because his subjective response might or might not be related to his objective output.

B. Subjective Outputs

The kinds of subjective outputs to be sought of the subject were as follows:

(1) Preference responses, e.g., I like/do not like the input.

(2) Utility responses, e.g., I can/cannot apply the input to system design.

(3) Knowledge responses, e.g., I understand/do not understand the input.

(4) Implication responses, e.g., I draw the following implications from the input; the following consequences result from the input.

(5) Schedule responses, e.g., the input is too early/too late/just in time.

(6) Impact (effect) responses, e.g., my design is/is not influenced by the input.

(7) Format responses, e.g., I would prefer the input to be in the following format.

Although there was some slight overlap among these responses, each of these response types was considered separately because they could be combined in different ways, such as understanding an input but rejecting it as being inappropriately timed.

C. Product Outputs

Because the study was concerned only with the basic design concept, product outputs were largely of an analytic or decision-making type, eg, determination of functions, specification of equipment characteristics and operating modes. These were expressed in terms of lists of functions to be performed by the system, equipment descriptions, equipment flow diagrams and procedures for operating the test equipment.

7. Determination of Specific Measures

Measures of the effect of MR and SD inputs on subsystem design include the following:

1. Number and skill level of personnel estimated as required by subjects.
2. Number and skill level of personnel required by subjects' designs.
3. Number and types of manually operated equipment required by subjects.
4. Number of automated equipments required.
5. Number and type of special purpose equipment.

6. Number of engineers in each group designing automated/ non-automated configurations.

7. Number and type of design changes made after manpower requirements are changed.

8. Number of controls and displays required by subjects.

9. Number of manual operations specified.

10. Inter-subject variability.

To understand the rationale for these measures, it is necessary to consider them in terms of the overall experimental design of the study. This study design and related measures are discussed in detail in the following section.

C. EXPERIMENTAL DESIGN

To explain the reason why the experimental design for this study was created the way it was and the reasons for the various analyses which were performed, this subsection has been organized in terms of the specific study goals listed in Section I.

1. Will differences in amount and timing of HRD inputs result in different design concepts?

The basic hypothesis was that engineers receiving highly comprehensive SOW's, including all the HRD inputs considered necessary for system design, would create design concepts different from those engineers who received incremental HRD inputs.

To test this hypothesis the eight subjects were divided into two groups of four. The Omnibus group received all of its inputs, including HRD, prior to beginning design. It received no additional inputs throughout the remainder of the study. The Incremental group received prior to beginning design a basic SOW, including all equipment inputs and, of the HRD inputs, only a minimally restrictive manning requirement. In sessions 3 and 4 the Incremental group received the remainder of its HRD inputs.

Presumably, if the difference in amount and timing of the HRD inputs influenced design, it would be reflected in the basic design concept the engineer created. In addition to the actual design output for a system which would implement design requirements, subjects were asked to decide which of three concepts (manual, semi-automatic, or automatic operation) would best solve the design problem. The overall subsystem design could then be evaluated to determine in which of the three categories it belonged. Differences between the two groups could be evaluated by comparing the frequency of particular types of design concepts produced by subjects. Where changes in treatment conditions occurred (ie, in sessions 3 and 4), it is possible to determine what modifications, if any, were made to the design output of sessions 1 and 2.

The effect of differences in amount and timing of HRD inputs could also be determined qualitatively by the following questions which were asked following the first design session:*

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* A complete list of questions asked after each design session is presented as part of Appendix I.

1. Did you have enough information in the SOW to develop the design concept?
2. Enough equipment information? Enough personnel information?
3. Is this equipment information characteristic of SOW's you work to?
4. Is this personnel information characteristic of SOW's you work to?
5. What information that you did not have would you wish to have?
6. Was the information in the SOW useful in helping you decide upon your system configurations? Has enough information been included in the personnel requirements statement? (For the Omnibus group only): What design implications would you draw from the personnel requirements?
7. What information would you ordinarily have at the start of design?
8. What items of information in the SOW particularly affected your design decisions? Why?
9. What was the effect of personnel requirements on your design concept?

At the conclusion of the second design session the following relevant questions were asked:

1. Have the equipment requirements acted in any way to constrain your design concept? If so, how?
2. Have the personnel requirements acted in any way to constrain your design concept? If so, how?
3. What equipment and personnel information which has not been provided to you would you wish to have? Why?

Individual session by session effects could be discerned by means of the responses to these questions.

A word about the rationale for these questions. It was considered possible that because they received only the basic SOW, the Incremental group might also feel that the minimally restrictive personnel requirement did not provide very useful information. One might also find that the different personnel requirements affected the design concepts of the two groups differentially.

2. Will quantity constraints produce different effects on design than quality constraints?

Manpower requirements are of two types: quantity (ie, number of personnel) and quality (ie, skill level). The previous study indicated that both of these requirements would exercise an effect only if they were formulated as constraints on design. The quantity requirement would therefore have to be phrased in the following manner: equipment must be designed so that no more than N personnel will be required to operate/maintain the equipment. The quality requirement would have to be phrased as: equipment must be designed so that it can be operated/maintained by personnel with a 3 (5, or 7) -level skill capability.

Two questions can be asked. One may ask whether one type of MR is more constraining than another. This question would be important in evaluating the relative emphasis to be placed on an MR in tradeoff decisions.

One can also ask whether a detailed stringent MR has more effect on system design than one which is phrased in general terms only.

In order to determine the differential effect of the two types of constraints, the two major groups (Omnibus and Incremental) were further subdivided into two halves. Two of the Omnibus and two of the Incremental subjects were asked to design to the quantity constraint. Two of the Omnibus and two of the Incremental subjects were asked to design to the quality constraints. The Omnibus subgrouping occurred in the first session; the Incremental subgrouping, in the third session.

This further subdivision produced the following subgroups:

O-N: Omnibus subgroup receiving only the personnel quantity constraint.

The requirement levied on this subgroup was as follows:

"5.1 Personnel Manning Requirements

Use of AGE for the maintenance and testing of any individual system, subsystem or component of the missile and associated missile-carrier aircraft shall not require more than two operators--one at or in the aircraft and one at the checkout or test equipment."

O-S: Omnibus subgroup receiving only the skill level constraint. The requirement levied on them was as follows:

"5.1 Personnel Manning Requirements

Equipment shall be designed to be operated by military technicians with an Air Force Speciality Code three-level skill only (see Appendix for definition of skill levels)."

Incremental Group

The Incremental group was not subdivided in the first two sessions. They received and functioned for the first two sessions under the following minimal personnel requirements:

"5.1 Personnel Manning Requirements

Equipment design shall minimize the quantity and skill level of military personnel required to operate the equipment."

3. Will the imposition of MR constraints affect equipment characteristics after the basic design concept has been developed?

The Air Force sometimes redefines its system requirements during the development of the system. The purpose of asking question (3) above is to determine the effect on design when such a reorientation occurs. Moreover, the effect of adding personnel requirements would help to indicate how influential MR constraints can be.

In the first two design sessions the Omnibus group had received differential MR constraints. Half the group was constrained to design to the 3-skill level (skill constraint or O-S group). The other half was constrained to design for a crew of two men (number constraint or O-N group). To test the effect of imposing additional design requirements, the subgroup constrained by the skill requirement (O-S) now also had to design for two men. The subgroup constrained to design for two men (O-N) now had also to design for a 3-skill level.

The additional requirements were added in the following manner:

"At this time the Air Force customer has decided to make his personnel requirements a bit more stringent than they were when you started your design.

"(O-N Group) If you look at section 5.1 of your SOW which describes operator requirements, you will see the following statement:

"Use of AGE for the maintenance and testing of any individual system, subsystem or component of the missile and associated missile-carrier aircraft shall not require more than two operators--one at or in the aircraft and one at the checkout or test equipment."

"In order to minimize the skill level of the personnel needed to operate the maintenance ground equipment, the Air Force has levied the following additional requirement upon you:

"Equipment shall be designed to be operated by military technicians with a three-skill level only." (Please refer to the definition of skill levels included in the Appendix to the SOW.)

"(O-S Group) If you look at section 5.1 of your SOW which describes operator requirements, you will see the following statement:

"Equipment shall be designed to be operated by military technicians with a three-skill level only."

"In order to minimize the number of personnel needed to operate the maintenance ground equipment, the Air Force has levied the following additional requirement upon you:

"Use of AGE for the maintenance and testing of any individual system, subsystem or component of the missile and associated missile-carrier aircraft shall not require more than two operators--one at or in the aircraft and one at the checkout or test equipment."

"In this session we ask you to review the design concepts you created previously in the light of the additional requirements imposed upon you, and to make such changes as you feel would be necessary to bring your design in accordance with the added personnel requirements."

At the conclusion of the session the following questions were asked:

1. Did the additional personnel requirements make any difference to your design? If so, what changes did you make?

2. What design implications did you draw from the added personnel requirements?

3. Are these added requirements too stringent? Easy to handle?

4. Was there enough information provided in the added requirement?

5. What information would you wish included in the personnel requirements section of the SOW?"

In the third session the Incremental group was subdivided in the same fashion as the Omnibus group in the first session. This produced the following subgroups:

I-N: Incremental subgroup receiving only the personnel quantity constraint.

I-S: Incremental subgroup receiving only the skill level constraint.

These constraints were levied in the following manner:

"In this session we are able to provide you with additional information secured from the Air Force. This information describes the personnel requirements to which you should design; in addition, the Air Force has made a number of analyses, included in an Appendix to the SOW, which describe what they think the maintenance technicians in the system under design would be doing.

"Please replace section 5.1 of your SOW which describes operator requirements with the following statement:

"(I-N Group) Use of AGE for the maintenance and testing of any individual system, subsystem or component of the missile and associated missile-carrier aircraft shall not require more than two operators--one at or in the aircraft and one at the checkout or test equipment.

"(I-S Group) Equipment shall be designed to operate by military technicians with a three-skill level only. (The definition of skill levels is included in the Appendix.)

"In this session we ask you to review the design concepts you created previously in the light of the additional requirements and information now provided, and to make such changes as you feel would be necessary to bring your design in accord with the more stringent personnel requirements."

At the conclusion of the session the following questions (among others) were asked:

1. Did the revised personnel requirements make any difference to your design? If so, what changes did you make?

2. What design implications would you draw from these requirements?

3. Are these requirements too stringent? Too easy?

4. (I-N Group) What level of skilled personnel would you need to have to run your system under the personnel requirements imposed? Why?

5. (I-S Group) What number of personnel would you need to have to run your system under the personnel requirements imposed? Why?

The effect of imposing these requirements on the subgroups could be tested by analyzing any changes made in subsystem design and also by responses to the questions asked following the design session.

4. Will the removal of MR constraints affect equipment characteristics after the basic design concept has been developed?

This question is parallel with that of question (3). If MR had earlier constrained equipment design, then removal of the MR should lead to design changes. Such design changes would provide additional evidence for the influence of MR on design.

To study this problem all personnel constraints were removed from all subjects in the fourth design session. Instructions were provided in the following manner:

"Up to this point in time you have designed your systems to rather stringent personnel constraints. In this session we would like you to consider that all personnel constraints have been eliminated. In other words, consider that you are able to design for an unlimited number of personnel and any skill level which you think you might need. Please review your design concepts from this standpoint. In the event that you restricted your designs to fit the personnel constraints, indicate what changes in your designs you would wish to make, now that these restrictions have been voided.

"(For incremental groups only: To help you in your design, additional information is now available from the Air Force describing its analyses of anticipated personnel characteristics and the tasks maintenance men would perform.)"

After the engineer had completed his task, the following questions were asked:

1. For incremental groups only: Did the additional information provided by the Air Force help any? Did it affect your design solution in any way? If so, in what way? If not, why not?

2. Did lifting the personnel restrictions influence you in any way in changing your designs? In what way? If not, why not?

3. We had made the assumption that the personnel requirements constrained your previous design in some ways. Is this true? How had these requirements affected your design?

4. Did your preferred design change any over the past four sessions when personnel requirements were changed? In what way? Why? If not, why not?

5. Do you feel that these personnel requirements are realistic? Unrealistic? Would you rather not be constrained in this way? Why not?

6. If you had to trade off personnel number and skill level, how would you do it? In other words, if you had a choice between fewer skilled technicians or more unskilled personnel, which would you prefer? If you had more highly skilled technicians, could you use fewer people? If you had fewer people, would a higher skill level make up for the small size of the crew?

5. Which HRD inputs are preferred and utilized by engineers and at what stage in system development?

Obviously it would be useful to determine which HRD inputs receive greater or lesser acceptance by engineers. Knowing this it would be possible to examine those inputs which were not being accepted in order to improve them.

An answer to this question could be derived in two ways: (a) through the responses made by subjects to the questions asked following each design session; and (b) through a paper and pencil test of HRD preference administered following completeion of the design.

The following questions asked following the design sessions are pertinent to the problem:

1. What design implications would you draw form the personnel flow diagrams; skill descriptions; from the QQPRI?
2. What equipment and personnel information which has not been provided to you would you wish to have? Why?
3. Are the skill level definitions understandable?
4. Did the additional information provided by the Air Force help any? Did it affect your design solution in any way? If not, why not?

To determine at precisely what stage of system development HRD inputs were most useful a questionnaire test (HRD Inputs Test) was developed. This is described in Section III.

6. How does the engineer's concept of manpower for his system relate to his design and how does this concept relate to more objective methods of predicting manpower (eg, Barton et al.'s (1964) queuing model)?

See APPENDIX III.

Summary of Experimental Design

The experimental design for the study can now be summarized in Table V which describes each of the two groups, the conditions under which they designed and the inputs provided to them.

In sessions 1 and 2 comparisons are made between the Omnibus and Incremental groups to test the effect of different amounts of HRD information and different personnel requirements (restrictive vs. non-restrictive).

TABLE V

EXPERIMENTAL DESIGN FOR STUDY

CONDITION	GROUP	SESSION 1	SESSION 2	SESSION 3	SESSION 4
Sub-group Break-down	Omnibus	O - N O - S	O - N O - S	O - N + S O - S + N	None
	Incremental	None	None	I - N I - S	None
Type of Manpower Requirement	Omnibus	Moderately Constraining	Moderately Constraining	Highly Constraining	None
	Incremental	Minimally Constraining	Minimally Constraining	Moderately Constraining	None
Amount of HRD	Omnibus	Comprehensive HRD	No Added Information	No Added Information	No Added Information
	Incremental	Partial HRD	Partial HRD	3rd Level & Personnel Flow Diagrams	Task Analysis and QQPRI

O-N - omnibus group, subgroup receiving only the personnel quantity constraint;
O-S - omnibus group, subgroup receiving only skill level constraint;
O-N+S - quantity subgroup receiving skill constraint also
O-S+N - skill subgroup receiving quantity constraint also
I-N - incremental group, subgroup receiving personnel quantity constraint
I-S - incremental group, subgroup receiving only the skill level constraint.

In session 3 the comparisons are as follows:

(1) Between the Omnibus group responses of session 3 and Omnibus group responses of sessions 1 and 2; to see if the added personnel requirements affect design responses;

(2) Between O-N+S and O-S+N responses in session 3; to see whether adding different personnel requirements produces a differential effect on design responses;

(3) Between the I-N and I-S subgroup responses of session 3 and the Incremental responses of sessions 1 and 2; to see if tightening up personnel requirements and providing added personnel information will change design characteristics;

(4) Between I-N and I-S responses in session 3, to study the effect of different personnel requirements.

In session 4 the comparison is between session 4 Ominbus and Incremental responses and those of earlier sessions; to see if removing personnel constraints will affect existing designs.

The experimental design associated different amounts of information with varying personnel requirements, so that the Incremental group not only had less HRD information than the Omnibus group, but also had a much weaker personnel requirement. As a consequence, it is impossible, except in a qualitative way, to differentiate the two conditions. The conditions were combined deliberately. Realistically, weak personnel requirements tend to accompany incremental HRD inputs. Although the reverse cannot be said to be true (i.e., that strong personnel requirements are associated with earlier HRD, primarily because this situation is almost never found in actual procurement), the latter situation represents an ideal which the authors considered useful to contrast with the present situation. The point is not whether differences in personnel requirements are more important than up-to-date HRD, or what the effect of each is separately, but whether, as a total input package comprehensive HRD plus strong MR will lead to more effective designs than the present system. What is being studied is a complex of factors, not single variables.

SECTION III

RESULTS AND CONCLUSIONS

A. INTRODUCTION

Before proceeding to the specific study results, it may be helpful to the reader if he refers to Appendix II, (page 117) which presents some representative design outputs which subjects produced and which will give him a better "feel" for the nature of the design process. The following is a list of outputs illustrated in Appendix II:

(1) Tradeoff Decision-Making Matrix;
(2) System description;
(3) Flow diagram of system inputs and outputs;
(4) Equipment operating procedure.

Because of the complexity of the study results, we will summarize the study results before we proceed to detailed results, in which the results are categorized by the individual questions which the study sought to answer.

TABLE VI

SUMMARY TABLE OF RESULTS

EXPERIMENTAL QUESTIONS

1. Will differences in amount and timing of HRD inputs result in different design concepts?

The answer is YES, as indicated below.

Group (4 designers each)	Design Concept	Manual Features	No. of Test Sets	Manpower Estimated by Subjects**	
				Quantity	Skill
Omnibus (all data in Statement of Work)	3 automatic 1 semi-automatic	166	22	21*	3-3 level 10-5 level 6-7 level 2-9 level
Incremental (data in stages)	3 semi-automatic 1 automatic	77	23.5	16	6-3 level 8-5 level 2-7 level 0-9 level

* Contains one "don't know". ** Includes both flight line and shop

This question is further discussed in paragraphs 1, 2, 3, 13 of the summary of results.

2. Will quantity constraints produce different effects on design than quality constraints?

The answer is YES, as indicated below.

Group (4 designers each)	Design Concept	Manual Features	No. of Test Sets	Manpower Estimated by Subjects ***	
				Quantity	Skill
Quantity Constraint	3 automatic 1 semi-automatic	103*	16.5	22	2-3 level 11-5 level 7-7 level 2-9 level
Skill Constraint	3 semi-automatic 1 automatic	133	29	15**	7-3 level 7-5 level 1-7 level 0-9 level

* Incomplete data on one subject
** Contains one "don't know"
*** Includes both flight line and shop.
This question is discussed further in paragraphs 4 and 12 of the summary of results.

3. Will the imposition of MR constraints affect equipment characteristics after the basic design concept has been developed?

The answer is YES, as indicated below.

Group	MR Constraint Added	Change	
		Yes	No
Omnibus	Quantity	xx	
	Quality	x	x
Incremental	Quantity	x	x
	Quality	xx	

This question is further discussed in paragraphs 7 and 8.

4. Will the removal of MR constraints affect equipment characteristics after the basic design concept has been developed?

   The answer is NO. This question is further discussed in paragraph 9.

5. Which HRD inputs are preferred and actually utilized by engineers and at what stage of development?

   Most HRD information and requirements should be provided at the start of design if they are to be utilized.

   This question is further discussed in paragraphs 5, 10 and 11.

6. How does the engineer's concept of manpower for his system relate to his design and how does this concept relate to more objective methods of predicting manpower?

   This question is further discussed in paragraph 6 and Appendix III.

B. SUMMARY OF RESULTS

1. Analysis of the types of subsystems developed by subjects indicates a substantial difference between the Omnibus and Incremental groups. Three of the four Omnibus designs were automatic; three of the four Incremental designs were semi-automatic. The difference between the two groups fails to be statistically significant, primarily because of the small number of subjects involved. However, it would appear that the timing and amount of HRD plus the different personnel requirements had some influence on the type of subsystems developed.

2. The Omnibus group also produced significantly (at the .005 level) more manual features in their designs than did the Incremental group. Differences between the two groups in terms of manpower required were also significant at the .08 level. There were no appreciable differences between the groups with regard to the number of test sets developed. However, the number of test sets developed by subjects ranged from 1 to 10, suggesting that one can expect in the normal design situation considerable variability in design solutions.

3. Six of the eight subjects (three in each group) reported that the personnel requirements imposed did affect their design decisions. However, as they saw the design situation, reliability, amount of work

required and time constraints were the primary factors in determining the type of subsystem developed. Personnel requirements on their own were not important enough to dictate design decisions, but did combine with other factors to force the design concept adopted.

4. The type of manpower requirement imposed also appeared to make some difference to subjects who were differentially constrained by number and skill level. The number of test sets developed was substantially greater for subjects receiving the skill restriction (.17 level of significance). Skill restricted subjects also produced more manual design features (at the .11 level). Skill restricted subjects also required fewer personnel with lower skill levels (significant at the .09 level). The latter two points, in particular, suggest that the skill restriction may be more influential on design than the number restriction.

5. As in previous studies, engineers selected their basic concept very rapidly. Only one of the subjects failed to establish his preferred design concept in the first session.

6. Subjects experienced little difficulty in determining a level of manning which they considered appropriate to the subsystem they had designed. Omnibus subjects in general required a higher skill level and a larger crew than did Incremental subjects, a finding which suggests that the MR and HRD inputs provided this group had some influence on their manpower estimates. Engineers feel that a higher level of skill and more personnel are required in the shop, primarily because more manual, troubleshooting functions are performed in the shop.

7. The additional HRD information provided to the Incremental group in the third session either resulted in a design change or would have assisted (had it been provided earlier) in developing the design concept.

8. The additional MR constraints imposed on the Omnibus group in the third session did require engineers to make some changes in design concept. However, the fact that engineers resist making design changes after their design has been formalized (also found to be true in previous studies) tended to reduce the extent of changes demanded by the new MR constraints. Much the same effect was found for the Incremental group.

9. Removal of the MR constraints did not in six cases out of seven cause changes in design concepts, although some subjects noted that if the MR constraints had originally not existed, their design would have been somewhat different. This result is entirely in accord with earlier studies which suggest the relative inflexibility of design concepts once they are formalized.

10. All subjects indicated that they would prefer most HRD information and requirements to be provided at the start of design. Failure to supply this information leads to some lack of clarity for engineer and non-utility of this information when provided later in design. The following items of personnel information are particularly desired as soon as possible:

(1) Maximum number of personnel for which equipment is to be designed;
(2) Description of jobs personnel will have to perform;
(3) Personnel skill level;
(4) Number and type of personnel to be made available to run the system.

11. Although engineers desire as much information about the system as possible, and although this information does affect their design concept, they have difficulty verbalizing design implications from the information. This suggests that it is necessary for the human resources specialist to specify for the engineer in the SOW the design implications of the HRD the former provides.

12. The engineer subjects in this study almost unanimously felt that skill was of greater significance to the operation of the system than the number of personnel available. Skill can compensate for lack of personnel, but additional personnel cannot compensate for lack of skill.

13. In general, the results of this study verify the hypotheses advanced as an output of the previous study: that amount, timing and nature of the personnel information supplied to design engineers will exercise some effect on the design concept.

C. DETAILED RESULTS

The effect of amount and timing of HRD inputs on design are summarized in Table VII and are described in detail in the following pages.

TABLE VII

THE EFFECT OF AMOUNT AND TIMING OF HUMAN RESOURCES DATA INPUTS ON DESIGN

Design Group (4 each)	Design Concept *	Average No. of ** Manual Features	Average No. of Test Sets	Average Manpower Required	
				Quantity	Skill Value
Omnibus (all data in SOW)	3 automatic 1 semi-auto.	50.3	5.5	5.5	38.5
Incremental (data in stages)	1 automatic 3 semi-auto.	17.5	6.0	6.0	42.5

* = difference significant at .23 level

** = difference significant at .005 level.

1. Will differences in amount and timing of HRD inputs result in different design concepts?

The answer to this question is determined by the nature of the system designs produced by subjects of the two groups. Subjects were asked at the start of the study to make tradeoff decisions among an automatic, semi-automatic and manual design.

In accordance with what has been learned previously concerning the speed with which basic design concepts are developed by engineers, (and the propensity for automatizing equipment) all subjects immediately rejected the manual design possibility. The reasons for rejecting the manual alternative were the reliability, maintainability and turn-around requirements.

Because of the rejection of the manual design alternative, the essential comparison is between the numbers of subjects selecting an automatic vs. those selecting a semi-automatic solution.

In determining which design concept was utilized, the investigators allowed subjects to characterize their designs; that is, subjects assigned the semi-automatic or automatic description to their own designs. These categorizations were later checked by the investigators against the actual subsystem design produced.

An automatic system was defined by subjects as a system in which the maintenance man merely initiated machine sequencing and observed the results. In a semi-automatic system the maintenance man initiated machine sequencing, but the machine ran only to a predetermined stage in its operation, after which the technician had to decide whether to continue the sequencing and, if there were alternative tests that could be made, to decide which test to run next.

If there were no consistent tendency on the part of subjects to select either a semi-automatic or an automatic design solution, one would expect the frequency of types of solution to be: (1) equal between the two groups (ie. the same numbers of automatic and semi-automatic solutions in both groups); (2) equally divided between semi-automatic and automatic (ie, each group would have two automatic and two semi-automatic solutions).

The design solutions for the individual subjects, together with the number of test sets they required for these solutions, are shown in Table VIII.

TABLE VIII

SUMMARY OF DESIGN SOLUTIONS

Subject	Group	System Type	Number of Test Sets
Y	I-S	Semi-automatic	4
L	I-S	Semi-automatic	10
F	I-N	Automatic	6
Mc	I-N	Semi-automatic	3-4
Mo	O-S	Semi-automatic	5
Ma	O-S	Automatic	10
K	O-N	Automatic	1
W	O-N	Automatic	6

When the actual frequencies of design solutions are compared statistically with the expected frequencies using the Fisher Exact Probability Test (Siegel, 1956), the result is a probability value of .23. The Fisher test, to quote the author,

> "is an extremely useful nonparametric technique for analyzing discrete data....when the two independent samples are small in size. It is used when the scores from two independent random samples all fall into one or the other of two mutually exclusive classes. In other words, every subject in both groups obtains one of two possible scores....The test determines whether the two groups differ in the proportion with which they fall into the two classifications..." (p. 97).

Although the .23 value is insufficient to reject the hypothesis that the system designs are the result of individual variability in subjects, it is necessary to qualify the answer somewhat. It should be noted that the two groups produced exactly reversed solutions, which suggests a non-random factor. Unfortunately, the statistical techniques available for making comparisons of discrete frequencies do not take into account the difference in direction of response between the two groups.

In considering the meaning of the statistical results, the following must be kept in mind. The differential treatments involving HRD inputs were only one factor determining the choice of a design solution. The primary factors affecting the design concept were the reliability, maintainability and time requirements, with the MR and HRD inputs providing only an increment to these factors. Verbally subjects indicated that MR/HRD inputs did influence their design decisions. Since the primary factors affecting the design concept will always be the equipment requirement, it must be considered that, to the extent that they reflect the influence of personnel inputs, the differences in the frequency of experimental design solutions are in reality very indicative. The point is that one cannot expect personnel requirements and inputs *in and of themselves* to determine design responses. To the extent that HRD inputs exercise *any* impact on design responses (as they did in this study), their effect was as significant as one could reasonably expect them to be.

Assuming that the differences in response frequency between the two groups are not merely random, it is necessary to explain them. Why should the Omnibus group have produced more automatic and the Incremental group more semi-automatic responses? Since the Omnibus group received more restrictive MR constraints, it would seem reasonable that these constraints would strengthen the subjects' tendency to automatize their equipment. The fact that they were required to design for two men or an Air Force Speciality Code (AFSC) of three-level would cause them to throw the largest part of the burden of system operation on the equipment. Both the number and skill constraints would have suggested the desirability of reducing the influence of the human in the subsystem.

On the other hand, the minimal MR constraint received by the Incremental group would have reduced (to a certain extent) the tendency to automatize their designs.

What evidence is there for these hypotheses, based on the subjects' verbal responses?

Six of the eight subjects reported that the MR constraints did affect their design solutions. The consensus of responses can be summed up as follows: the tasks required and the personnel constraints imposed, when combined with the time requirements, seemed almost to dictate a particular level of automaticity. The level of personnel to a certain extent constrained the level of automaticity selected.

One characteristic of design which never fails to surprise is the great degree of variability found in the more detailed aspects of the design solutions selected to answer the same requirements. This can be seen by referring again to Table VI. The number of individual test sets ranged from one to ten. Unfortunately, the number selected did not differentiate between the Omnibus and Incremental groups; both groups had a very similar range.

Other indices of variability: One subject packaged all his test sets in a single cart; another had individual test sets which had to be hooked up with cabling before the tests could be run. Some test sets were individually packaged; others were individually packaged but placed in a van or on a cart.

The implication of this variability for the writer of design specifications or procurement documents is that as much detail as possible is needed to restrict this variability. Since design is so variable, the procuring agency cannot be sure of getting the design it wishes unless it attempts to restrict this variability very severely by specifying as clearly as possible what it expects from the designer.

With regard to the amount and type of information provided in the SOW on the basis of which the designs were developed, the following was reported:

Half the subjects stated that the level of information provided in the SOW was very similar to that they are ordinarily given to work with, while the other half indicated that it was much more complete than they were accustomed to. Apparently there is great variability also in the format and detail of existing procurement specifications to which engineers must design.

Subject responses indicated that they hardly, if ever, received any data regarding personnel. In some cases they have to generate the information themselves. While it cannot be said that the personnel information was of major significance in affecting design decisions, for certain subjects it was helpful. One subject found the descriptive material in the QQPRI to be helpful in developing operational procedures for his design. Another reported that "personnel had a great deal to do with how I design" and so presumably the information provided was of use to him.

The fact that most of the subjects reported that the HRD inputs did not significantly affect their designs must be considered in the light of their responses to the equipment information, which they also said had little effect, except for system and checkout complexity and required turn around time. The point is that except for explicitly stated requirements engineers do not really know (or at least cannot verbalize) what items of information (either equipment or personnel) really influence their design. They are unable to indicate what items of information, except for minor specific details, they would like to have in order to begin designing.

Another measure which was applied to the subjects' design outputs also indicated significant differences between the two groups. It will be recalled that among the measures to be applied to the design outputs (see Section II) were number and types of manually operated equipment, number of controls and displays required and number of manual operations specified. Since the number of instances of each of these measures was fairly small, it was considered desirable to combine all of these instances into a single measure. The results are shown in Table VII. A "t"-test indicates that the difference between the two groups is statistically significant at the .005 level, even though one of the subjects of the Omnibus group had incomplete data.

It may appear strange that the Omnibus group, which produced most of the automatic designs, should also have indicated significantly more manual design features (automaticity and manual features being somewhat inconsistent). This is not a contradiction, but rather a reflection of what appears to be a greater awareness on the part of the Omnibus group of the need to consider operator features. (This greater awareness might have been predicted as a result of the presentation of all HRD inputs - including stringent manpower requirements- at the start of design, which presumably alerted these subjects to the "customer's" interest in operator factors.)

As a consequence, Omnibus subjects were more painstaking about detailing the manual characteristics they needed for their systems, even though they may have needed fewer of them. The Incremental subjects, on the other hand, did not describe in as much detail the manual characteristics implicit in their designs. Hence the differences reflected in Table IX indicate a difference in sensitivity to operator factors, rather than a difference in design. This added sensitivity is of course essential to secure adequate consideration of personnel requirements, and is the reason why elsewhere the authors have suggested that the presentation of as much HRD as possible (whether or not these serve to constrain design) is useful.

Differences between the Omnibus and Incremental groups are not significant when one considers the number of test sets required by subjects (see Table VII). The mean number of test sets for the Incremental group is 6.0, while the mean number for the Omnibus group is 5.5. However, there are substantial differences between the individual subgroups which will be discussed under question (2).

Another measure referred to in Section II dealt with the number and skill level of personnel estimated as required by subjects. These will be analyzed in greater detail under question (6), which asks how the engineer's manpower concept relates to his design; but it is interesting to see whether the groups receiving different amounts of HRD at the start of design also differ in terms of the manpower they require.

For this analysis a manpower rating value was determined for each subject. This was secured simply by multiplying the number of personnel the subject indicated that he required times the skill level of those personnel. For example, if a subject said he needed two 5-level and one 7-level personnel to run his subsystem, he would receive a value of 17 ($2 \times 5 + 1 \times 7 = 17$). Although this method of quantifying manpower is highly arbitrary, it does serve to illustrate major differences between the two groups.

Table X lists the manpower values for each subject. When the Kruskal-Wallis One-Way Analysis of Variance test (Siegel, 1956) was applied to the data, the results are statistically significant at about the .08 level ($H = 3.5$; $H = 3.84$ for .05 level). The results suggest that the two groups are indeed differentiated in

TABLE IX

SUMMARY OF MANUAL DESIGN FEATURES

Subject	Group	System Type	Number of Manual References
Y	I-S	Semi-automatic	17
L	I-S	Semi-automatic	15
F	I-N	Automatic	25
Mc	I-N	Semi-Automatic	13
			Total = 70, M = 17.5
Mo	O-S	Semi-automatic	43
Ma	O-S	Automatic	58
K	O-N	Automatic	50
W	O-N	Automatic	*
			Total = 151, M = 50.3

* Incomplete Data

TABLE X

SUBJECTS ESTIMATES OF MANPOWER REQUIRED (FLIGHT LINE AND SHOP)

Subject	Group	System Type	Manpower Value *
Y	I-S	Semi-automatic	18
L	I-S	Semi-automatic	12
F	I-N	Automatic	20
Mc	I-N	Semi-automatic	22
			Total = 72, M = 18.0
Mo	O-S	Semi-automatic	23
Ma	O-S	Automatic	20
K	O-N	Automatic	52
W	O-N	Automatic	34
			Total = 129, M = 32.2

* Manpower value = Number x skill level.

terms of the manpower they require. Again the Omnibus group, which received all its HRD inputs at the start of design, required substantially more and higher skilled personnel. One can hypothesize that the greater amount of HRD information provided to the Omnibus group at the start of design emphasized the importance of manpower to the subjects of that group, and caused them to demand a larger number of skilled personnel (despite the fact that most of their subsystems were automatic).

The preceding analysis (Table X) was based on the subjects' own estimations of the manpower they felt they needed for their systems. In another analysis each design concept was analyzed by a human factors specialist not on the study team* and the number and skill level of personnel which that design concept would have required was determined. In other words, this manpower analysis was independent of the subjects' own estimates. Table XI shows the results of that analysis for the shop activity (all flight line designs required the same number and skill level, one 7-level, one 9-level).

Manpower required by Omnibus group designs was somewhat, although not significantly, less than that required by Incremental group designs, according to the Randomization Test for Independent Samples (Siegel, 1956). This is in accordance with the hypothesis that extensive HRD information plus stringent manpower requirements supplied at the start of design should result in more efficient design (from the standpoint of MR requirements) than incremental inputs and minimal manpower requirements.

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* The authors are grateful to Mr. E. A. Thompson of the Bunker-Ramo Human Factors Department, for performing this analysis.

TABLE XI

HUMAN FACTOR SPECIALISTS ANALYSIS OF DIFFERENCES IN MANPOWER REQUIRED BY SUBJECT DESIGNS

Subject	Group	System Type	Number (N) Required x Skill (S) Level Req'd		Manpower Value (N x S)
Y	I-S	Semi-automatic	1 x 5-level 3 x 7-level	=	26
L	I-S	Semi-automatic	2 x 7-level 1 x 9-level	=	23
F	I-N	Automatic	2 x 5-level 3 x 7-level	=	31
Mc	I-N	Semi-automatic	1 x 5-level 3 x 7-level	=	26
					M = 26.5
Mo	O-S	Semi-automatic	1 x 5-level 4 x 7-level	=	33
Ma	O-S	Automatic	1 x 5-level 2 x 7-level	=	19
K	O-N	Automatic	2 x 5-level	=	10
W	O-N	Automatic	4 x 7-level	=	28
					M = 22.5

Note: Table represents analysis for shop activity only; all flight line displays required the same number and skill level, one 7-level, one 9-level.

2. Will quantity constraints produce different effects on design than quality constraints?

Question (2) asks whether there are differences between the subgroups, regardless of the major group treatments. In other words, regardless of the amount and timing of HRD inputs, are there differences between subjects receiving the skill restriction (design only for 3-level personnel) and those receiving the quantity restriction (design for a maximum of two men). A comparison must therefore be made between I-S and O-S subjects on the one hand and I-N and O-N subjects on the other. To make these comparisons the reader should refer to Tables VII, VIII and IX.

In Table VII the measure of interest is the number of test sets required. In both Omnibus and Incremental groups the mean number of test sets required by subjects receiving the skill restriction is substantially greater than that required by subjects receiving the number or quantity restriction. However, this difference is statistically significant at the .17 level only (using the Randomization test for two independent samples (Siegel, 1956).

In Table VIII, comparing the manual design features included in subjects' designs, the differences between the sub-groups appears to be submerged by the over-whelming effect of the differences in amount and timing of HRD information provided. In any event, the fact that only incomplete data are available for one of the subjects of the Omnibus group makes a statistical comparison highly tenuous. Nevertheless, the differences are statistically significant at the .11 level (Randomization test for two independent samples (Siegel, 1956).

In Table IX, differences in manpower required by subjects to run the subsystems designed, major differences are found between the groups constrained by skill and those constrained by personnel number. Skill-restricted engineers tended to require fewer and less highly skilled personnel. This is in accordance with the manpower requirements imposed on these subjects. The differences are statistically significant at the .09 level (Randomization test for two independent samples (Siegel, 1956)).

There appears then to be some quantitative evidence that types of MR constraint produce differential effects on design responses, but further investigation is required if a definitive answers is to be given to this question.

Qualitative data are also available from responses to question number 6 in the fourth session. This question asked subjects generally how they would trade off skill against quantity of personnel. The responses given were as follows:

Y: Skill level can compensate for numbers, but not vice versa.

L: Must be designed for the lowest level of personnel, but raising skill level does not compensate for lack of personnel in operational systems.

F: Would prefer to see systems operated by a lesser number of skilled people and believes that skill can compensate for number.

Mc: Fewer skilled people are "greatly preferable" to numerically more unskilled people.... Too many unskilled people are a burden on the skilled people because they must supervise and train the unskilled.

Mo: Similar to Y's response above.

Ma: Skill is the most important factor.

K: "How much work do I have to do is how many hands I need" is the factor which allows him to arrive at how many "hands" he would need because of simultaneous jobs. Then "you look at whether you can reduce the number of hands with higher skill levels or design changes."

W: Skill can replace number.

It would appear then that although engineers do not view skill and number as a black and white dichotomy, most of them assign a higher priority to skill; and, faced with a quantity/quality tradeoff, would almost always opt for higher quality.

3. Will the imposition of MR constraints affect equipment characteristics after the basic design concept has been developed?

The responses made by subjects to the manpower requirements added in session 3 indicated quite positively that these requirements did or would influence design. Table XII indicates that six of the eight subjects would change their designs in various ways. However, the influence of these added requirements was only moderate, because of the well known resistance of engineers to modifying their design once it has been fully conceptualized. The results of session 3 indicate once more the potential influence of stringent personnel requirements on the design process.

TABLE XII

DESIGN CHANGES RESULTING FROM ADDITION OF MR CONSTRAINTS

				Type of Change			
Subject	Group	Type of MR Constraint Added	No Change	Simplify Design	More Manual	More Sophisticated	Not Specified
Y	I-S	N		X			
L	I-S	N	X				
F	I-N	S				X	
Mc	I-N	S			X		
Mo	O-S	N				X	
Ma	O-S	N					X
K	O-N	S	X				
W	O-N	S				X	

The following characteristic responses were made: "I might be able to simplify my design somewhat"; "would probably give more attention to automating the system than I did originally", because of "number of functions to be performed" and "limited time to be performed in"; "system would change to be a bit more manually oriented" (in order to accomplish the continuity testing he would simplify his checkout equipment); "would add more sophistication to my equipment"; "would reduce the amount of information fed back to the technician on the flight line and place more emphasis on the shop personnel".

There appear to be no significant inter-group differences in effect of adding MR constraints.

4. Will the removal of MR constraints affect equipment characteristics after the basic design concept has been developed?

In general, the removal of the MR constraints once the system had been designed to personnel restrictions did not cause the engineer to modify his design. Six of the seven subjects responding (one refused to reply) indicated that lifting the MR restrictions did not influence their design. One subject reported that he could now "get by with a simpler system with lower cost," etc. The system would be more manual, ie, "more buttons to push". He could proceed to a lower level of maintenance and component replacement.

5. Which HRD inputs are preferred and actually utilized by engineers and at what stage of development?

It is obvious from the results discussed previously that MR constraints, viewed as a type of HRD input, are utilized by engineers and do influence their design to a certain extent. Is this true of other HRD inputs?

Two sources of data are available relative to this question. At the conclusion of the design period a number of paper and pencil tests were administered to subjects (described in Meister et al., 1969), one of which (HRD Inputs Test) sought to determine at what stage of system development various HRD inputs would be most acceptable to engineers. The results of that test, expressed in terms of frequency of engineers preferring to receive inputs at various times, are shown in Table XIII.

The X^2 technique was applied to determine whether the distribution of subject responses among the four time periods varied significantly from chance. The distribution of six of the data items was significant at the .05 level or better.

TABLE XIII

PREFERENCE FOR HRD INPUTS AT SYSTEM DEVELOPMENT STAGES

Information	In RFP or Initial SOW	During Predesign	At Start of Detail Design	During Detail Design	X^2	P
1. Maximum number of personnel for which equipment is to be designed.	7	1			17.0	.001
2. Description of jobs personnel will have to perform.	6	2			12.0	.01
3. Personnel skill level.	6	2			12.0	.01
4. Type and length of training personnel will have.	4	3		1	5.0	NS
5. Amount of experience personnel will have.	4	3	1		5.0	NS
6. Duration of each personnel job.	5	2		1	7.0	.10
7. Number of personnel to be made available to run system.	6	1		1	11.0	.02
8. Type of personnel to be made available to run system.	6	1		1	11.0	.02
9. Cost of training personnel.	3	1		1	3.5	NS
10. Manpower life cycle cost.	4	1		1	5.0	NS
11. Probability that personnel will make certain kinds of errors.	2	6			12.0	.01
12. Equipment characteristics required by personnel characteristics or tasks.	4	3	1		5.0	NS
13. Criticality of tasks performed by personnel.	5	2		1	7.0	.10
14. Difficulty level of tasks.	1	2	1	1	3.0	NS

For those items which reflect little consistency on the part of subjects and are relegated to later stages of system development (ie, cost of training personnel, manpower life cycle cost, difficulty level of tasks), subjects indicated that these items are of little importance in the performance of their design tasks; hence they are not concerned with receiving this information immediately. Indeed, certain subjects refused to respond to a number of items on the ground that the item was an Air Force responsibility and not a contractor responsibility.

The following items of personnel information are, however, desired as soon as possible:

(1) Maximum number of personnel for which equipment is to be designed;
(2) Description of jobs personnel will have to perform;
(3) Personnel skill level;
(4) Number of personnel to be made available to run the system;
(5) Type of personnel to be made available to run the system.

In general it can be said that engineers prefer to receive as much HRD information as possible. Corroborating data can be found in the verbal responses of Incremental subjects in the third session. Two reported that they do not ordinarily receive this type of information; of the other two, one said that the ordinarily expects to have to "generate" this kind of information on his own, while the second said he "would almost have to receive this kind of information to do the job decently."

Another individual in session 3 indicated that presentation of HRD information earlier in the design time frame would have allowed him to reach his design decisions earlier and easier.

It is important to note that engineers respond primarily to inputs phrased as design requirements, and hence, with the exception of MR, HRD inputs held little value to them. At the same time engineers want to see as much information as possible, so they can pick and choose whatever they wish from it.

In general, even when the engineer says that he does not use personnel inputs, they create a context or bias toward one kind of solution or another. If one wishes, then, to have engineers pay more attention to personnel factors, it is desirable to provide them with considerable HRD information.

6. How does the engineer's concept of manpower for his system relate to his design and how does this concept relate to more objective methods of predicting manpower?

It was possible to secure manning estimates from all but one subject as the conclusion of session 1. These are shown in Table XII below, together with revisions made during the course of their design. F stands for flight line, S for shop.

Examination of Table XIV reveals some interesting differences between the Omnibus and Incremental groups. The Incremental group unanimously postulated two men for the flight line and two for the shop. These were at the 3 or 5 level (with only one exception, a 7-level for the shop). Changes in Incremental group manning as a result of new HRD inputs were minor.

In contrast the Omnibus group postulated somewhat higher numbers of men required, particularly for the shop. A comparison of Incremental vs. Omnibus estimates for shop manpower (quantity) alone, using the X^2 technique, reveals that the difference is significant at the .06 level. Skill levels were also somewhat higher. The larger manning required by Omnibus subjects is attributed to their greater sensitivity to the "customer's" interest in personnel factors (resulting from the large number of HRD inputs presented at the start of design). The distribution of (revised) skill levels, broken out by group and by type of system designed, is shown in Table XV.

The following conclusions appear warranted:

1. Engineers can develop estimates of the manning needed for their systems, but in a number of cases these estimates are not very precise. It is apparent that they need expert help in developing these estimates.

2. Engineers feel that a higher level of skill and more personnel are required in the shop situation, primarily because they conceived more manual, troubleshooting functions being performed in the shop.

3. Manpower estimates, as the engineer sees them, seem to be more highly related to the type of subsystem he designs than to any imposed personnel constraint based on questions following design sessions. Flight line estimates of skill varied significantly (at the .05 level) from what was required by the skill constraint.

One would expect the automatic subsystems would elicit estimates of fewer personnel or lower skill level, but this hypothesis was not reflected in subject estimates. For example, there is a clearcut difference between skill levels predicted for semi-automatic and

65

TABLE XIV

MANPOWER ESTIMATED BY SUBJECTS FOR EXPERIMENTAL SUBSYSTEMS

Subject	Group	System Type	Original Manning	Revised Manning	HF Analysis Shop *
Y	I-S	Semi-auto.	F: 2-(3-level) S: 1-(5-level)	2-(5-level) 2-(1, 5-level; 1, 3-level)	2-(1, 5-level 1, 3-level)
L	I-S	Semi-auto.	F: 2-(3-level) S: Don't know	2-(3-level)	2-(7-level) 1-(9-level)
F	I-N	Automatic	F: 2-(5-level) S: 2-(5-level)	No change No change	2-(5-level) 3-(7-level)
Mc	I-N	Semi-auto.	F: 2-(1, 3-level; 1, 5-level) S: 2-(7-level)	No change No change	1-(5-level) 3-(7-level)
Mo	O-S	Semi-auto.	F: 2-(Skill level Unknown) S: 2-(Skill level unknown)	2-(3-level) 3-(2, 5-level; 1, 7-level)	1-(5-level) 4-(7-level)
Ma	O-S	Automatic	F: Don't know S: Don't know	F: 2-(5-level) S: Don't know	1-(5-level) 2-(7-level)
K	O-N	Automatic	F: 2-(1, 5-level; 1, 7-level) S: Unspecified	F: 2-(1, 3-level; 1, 5-level) S: 6-(2, 9-level; 3, 7-level; 1, 5-level)	2-(5-level)
W	O-N	Automatic	F: 3 (Unspecified) S: Don't know	F: 3-(2, 5-level; 1, 7-level) S: Same	4-(7-level)

* Note: Flight line manning remained constant at 1-(7-level), 1-(9-level).

automatic subsystem designs with automatic designs requiring higher skill personnel. This is particularly marked at the shop level, where the distribution of skill levels estimated by subjects varied significantly (at the .02 level) from what would have been expected on the basis of the skill constraints.

These results are similar to those found in the study by Meister et al., 1968, in which a wide discrepancy between type of system designed and manpower requirements was also found. The question can therefore be raised as it was in the previous study whether designer estimates of required manpower are realistic, despite engineers' insistence that estimated manning is actually essential to operation of their systems.

4. It is noteworthy that the MR limiting manpower to two was violated in several instances, the designers either ignoring it or classing it as unrealistic although in general it was compiled with. An unanswered question is whether the number restriction to two men was actually effective in those cases in which this number was not violated, or whether the nature of the system designed was such that for these system designs only two personnel were needed. Engineers feel that they are responsive only to the nature of the systems they design, although other evidence (discussed under question (2)) suggests that they are unconsciously influenced by MR.

It is interesting to note also that compliance with the personnel quantity restriction was far greater than compliance with the skill quality restriction. This may be related to the engineers' well known difficulty in understanding the meaning of the skill requirements. Certainly skill estimates were more difficult for engineers to develop than were the number estimates.

5. The skill level requirement restricted manning to 3-level personnel. It is significant that almost all subjects violated this restriction. If one compares the skill levels estimated by subjects who were skill restricted with the skill levels estimated by subjects with the quantity restriction, there is some evidence (of a tentative nature only, of course) that subjects on whom the skill restriction was imposed had fewer higher level skills even when they violated the requirement. From that standpoint it can be said that the skill level restriction was somewhat effective.

6. An independent estimate of the manning required for this subsystem was performed by a Bunker-Ramo human factors specialist* not involved in the project and using only the basic SOW (excluding

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* Mr. E. A. Thompson of the Bunker-Ramo Human Factors Department

TABLE XV

DISTRIBUTION OF ESTIMATED MANPOWER BY GROUP, MAINTENANCE AREA AND SUBSYSTEM TYPE

Skill Level by Group

Flight Line Skills

	3	5	7	9	Total
I-S	2	2			4
I-N	1	3			4
O-S	2	2			4
O-N	1	2	1		4
Total	6	9	1		16

Shop Skills

3	5	7	9	Total
3	1			4
	2	2		4
	2	1		3
	3	4	2	9
3	8	7	2	20

Skill Level by System Type

Flight Line

	3	5	7	9	Total
Semi-Auto.	5	3			8
Auto.	1	7	1		9
Total	6	10	1		17

Shop

	3	5	7	9	Total
Semi-Auto.	3	3	3		9
Auto.*		5	4	2	11
	3	8	7	2	20

* Includes one "Don't know" response.

any personnel requirements and information) as the basis for his estimates. Manning was estimated for both automatic and semi-automatic configurations, as follows:

	Automatic	Semi-Automatic
Flight Line -	2 men, both 5-level	2 men, one 5, one 7-level
Shop -	2 man, both 7-level	2 men, both 7-level

It should be noted that the skill levels estimated by the human factors specialist agree far more with Omnibus group estimates than they do with Incremental estimates (see Table XVI). If we take the independent estimate as the "true" manpower required by these subsystems, the violation of the skill constraint by the Omnibus group is now much more understandable. If we assume the estimates made by the independent human factors specialist are more realistic than that permitted by the skill constraint, then the Omnibus group subjects were realistic in violating the skill constraints imposed on them. It is possible that in violating the skill constraint to a greater extent than the Incremental group, the Omnibus group was reacting to the additional HRD information they possessed, which suggested an increased task complexity.

TABLE XVI

COMPARISON OF THE DESIGN ENGINEERS ESTIMATE
OF SUBSYSTEM MANPOWER WITH HUMAN FACTORS ANALYSIS
OF SUBSYSTEM MANPOWER REQUIREMENTS

Designer	Design Engineer's Own Estimate		Human Factors Analysis	
	Quantity	Skill "Value"	Quantity	Skill "Value"
Y	4	18	6	42
L	4	12	5	39
F	4	20	7	47
Mc	4	22	6	42
Mo	5	23	7	49
Ma	2(inc)	10(inc)	5	35
K	8	52	4	26
W	3(inc)	17(inc)	6	44
Average	4.5	21.7	5.7	45.0

7. A comparison of subject manpower estimates with those produced by more objective means (eg, Barton et al., (1964) queuing model) is discussed in Appendix III.

What can one conclude from this examination of manpower estimates? It cannot be said that the personnel restrictions imposed were outstandingly successful in forcing engineers to work within these limits. In some cases engineers felt the restrictions were unrealistically stringent and could be complied with only by forcing a very costly design. Others did not express this opinion.

The authors would like to offer an hypothesis at this point. It is that engineers do not respond explicitly to personnel requirements (or, for that matter, to equipment requirements), but only in a general way. It will be recalled that six of the eight subjects reported that the personnel requirements did influence their design (and by extension their manpower estimates). On the other hand, when questioned specifically about the influence of personnel requirements, they did not feel that these requirements played a major role in their design, pointing to reliability, system complexity and turn-around time requirements as the basic factors influencing their designs. The fact that a personnel requirement is imposed on engineers does not mean that they will necessarily design to the letter of those personnel limitations, but that they will take the personnel factor into greater account than they would if no personnel requirement had been imposed at all. This would account for their violation of manpower limitations in their estimates, and at the same time for the fact that subjects restricted to a lower skill level had lower skill level estimates than those not so limited. From that standpoint the existence of a personnel constraint serves as a sort of benchmark to the engineer, who then tends to work within the general area of the mark even though he may deviate from it upon occasion. The same element may be present in the presentation of HRD inputs. Regardless of the attention paid by engineers to specific HRD items, they still view the existence of the inputs as evidence that the procuring agency wishes them to pay more attention to personnel factors than they would otherwise. From that standpoint, too, the more HRD information supplied to the designer, the more conscious he will be of the need to consider personnel limitations in his design.

Admittedly the fact that specific personnel requirements have only a general effect on design is somewhat frustrating, but it represents rather accurately, more so than the vague generalities sometimes expressed in articles on the design process, the manner in which the engineer designs. Specific hardware requirements, like reliability, do have a more measurable effect (hence a seemingly greater effect), but even with such specific hardware requirements, the range of responses one finds (as was discovered in the 1968 study) indicates that hardware requirements are not completely effective either.

SECTION IV

RECOMMENDATIONS

It appears quite clear now, as a result of the present study and the one preceding it (Meister, et al., 1968) that HRD inputs supplied to design engineers incrementally, following the issuance of the RFP/SOW, will have little, if any, effect upon the design concept. The basic design concept is largely fixed within a short time after the issuance of the SOW. Although there is no guarantee that the engineer will use HRD inputs even when they are presented under optimal conditions, it is quite clear that the present method of supplying them incrementally reduces the probability of their being used.

Moreover, if the human resources specialist expects any consideration to be given by the engineer to his inputs, these inputs must be phrased as design constraints, they must be comprehensive and expressed in such a way that the engineer understands the design implications of these inputs.

The situation is by no means as bleak as the preceding paragraphs might suggest. Phrased properly and provided on a timely basis, HRD inputs do exercise some influence on design. The more design-relevant these inputs are, the more influence they have.

The problem is one of being able to supply meaningful Human Resources design relationships. If appropriate personnel inputs (i.e., meaningfully related to design) are supplied to the engineer, he will use them. The format of the inputs is less important then their content.

At the very least the RFP and the SOW must include the following:

(1) Description of the manning structure for which the equipment is to be designed. Requirements must be specified for:

(a) Maximum number of operating/maintenance personnel allowed to be in the crew by job position. It should be clearly specified that any system configuration requiring personnel in addition to that number will be unsatisfactory.

(b) Maximum skill level allowed for each job position. This skill level should be related to the specific tasks to be performed by personnel in the new system.

(c) The function and task capabilities of these personnel.

(2) The design implications of the above must be clearly expressed.

Although a few procurement documents do include information on the manning structure for new systems, none of them indicates the design implications. Indeed a major weakness of human resources support data (SD) is that few, if any, design deductions are drawn from the task, time-line and QQPRI analyses which make up those data.

Additional research is needed regarding a number of problems. (1) Methods are needed for determining early during the conceptual phase of a system the "likely" manpower force to be available during the time period when the system would become operational. This "likely" force would be derived from sources such as phased out systems, career personnel, new enlistees and current training courses. (2) Techniques are needed for comparing the "likely" force with alternate forces of varying quantities and skill distributions and determining their impact on the cost, capability, reliability, availability, etc. of the system. Ultimately a "desired" manpower structure would be proposed for the system. (3) The design implications of manpower requirements need to be fully developed, so that the design concepts and characteristics which will yield the "desired" manpower force can be specified in the contract statement of work. For this research to have maximum validity it should study the performance of personnel at operational sites in relation to the design concepts of the system. (4) Methods are needed for periodically testing the design during conception and development for compliance with the nampower requirement constraints. (5) In addition to these improvements in HRD methodology, a document is needed which could be used to supplement the SD analyses by specifying their design implications. Such a document would then be used not only by the human resources specialist to make design recommendations, but also by the Air Force manager and engineer to extrapolate the HRD inputs provided to specific design relationships.

APPENDIX I

ABBREVIATED SCENARIO OF EQUIPMENT AND PERSONNEL INPUTS PROVIDED TO ENGINEER-SUBJECT

NOTE TO THE READER

The length of some of the equipment and personnel inputs provided to engineer-subjects in this study is so extensive that to have included all inputs in their entirety would have made this report extremely unwieldy. Consequently, less important inputs have been compressed by reproducing only that material which is illustrative of the general character of the input. Inputs considered by the authors to be of major importance have been reproduced in their entirety.

Where the purpose of a particular input or part of an input may have been unclear without additional explanation, explanatory material has been added in brackets.

INTRODUCTORY SESSION

Instructions for Participating Engineers

The United States Air Force, through a contract with the Bunker-Ramo Corporation, is conducting a study to determine how engineers make use of the information they are given (or develop themselves) to design a subsystem. Since any subsystem is composed of two basic elements, equipment and people, we assume that the engineer has available to him two kinds of information: information about equipment requirements, characteristics, functions, etc; and information about or relevant to the personnel who will operate and maintain that equipment.

The Air Force is interested in the engineer's use of both types of information, but it is particularly interested in the use made of personnel information. The reason is that although the engineer is accustomed by training and experience to using equipment information, personnel information may be relatively unfamiliar to him. The Air Force is interested in finding out if the personnel information it supplies to the engineer is used by him, and especially if that information makes a difference to the overall subsystem design.

To answer these questions, it is necessary to present this information in the context of the development of subsystem. Short of actually conducting the study during the development of actual equipment, which would take an excessive length of time, the only other way of creating a developmental/design context is to reproduce or simulate the development of a subsystem in a highly abbreviated form. This simulation will naturally have to be of the paper and pencil variety. However, this does not concern us too much since we are interested in studying the very early design phases, before detailed drawings are made and equipment fabricated.

What we have done is to take an already developed (operational) subsystem, extract the items of information used in its development and arrange them in a sequence which corresponds to the way in which they were actually used to design that subsystem. The subsystem selected by the Air Force is the ground maintenance subsystem for an air-to-ground missile carried by a B-52 bomber. The reason you were selected as subjects for this study is because you have helped to design similar ground maintenance subsystems.

Obviously, such a maintenance subsystem is a very large one, and it would be impractical to ask you to try to design the entire subsystem. What we have done is to ask you to consider in your design only the electrical components of the ground maintenance equipment. Consequently, we have arbitrarily simplified the subsystem by ignoring certain equipments and operations which you, who are experienced in the design of such subsystems, will obviously note. Do not be disturbed by this. The subsystem is supposed only to represent maintenance subsystems in general.

At the close of this introductory session you will be given design statement of work which contains certain equipment and personnel requirements and information. On the basis of these design requirements, plus additional information which you will receive at the start of each subsequent session, you will design a ground maintenance subsystem which best meets the requirements in your statement of work.

Since you are performing a conceptual design study, we ask you to consider three possible design concepts: one appropriate to a manual system, one for a semi-automatic system, one for an automatic system. Although any definition of these terms can only be loose at best, we define a manual system as one requiring a rather extensive involvement of personnel in the system operation. An automatic system is one which requires relatively little personnel involvement, and a semi-automatic system involves equipment and personnel functioning in about equal amounts.

We ask you to consider the design requirements in terms of all three system configurations and to describe the system you would design if you decided to go automatic, semi-automatic or manual. We will also ask you to trade off the various equipment and personnel factors involved in each configuration and tell us why you selected a particular configuration as being the best. You will also tell us which items of information you found most useful and why.

Since we will have only 4 working sessions, and since designing a complete subsystem is a big job, we will ask you to go into only enough detail to indicate the general character of the equipment you would design or purchase. We particularly want to know such things as:

(1) How many and what types of equipment (both special purpose and off-the-shelf) will be used by system personnel;

(2) The outstanding characteristics of that equipment and how they are intended to function;

(3) How the equipment will be used by personnel;

(4) How many men and of what type will be needed to use the system.

You will not be asked to develop detailed equipment drawings. However, you should sketch any equipment to be designed in enough detail to let us know what you have in mind.

One thing I should emphasize. The questions we ask and the tasks we ask you to perform are not tests in the conventional sense of the work. The word "test" suggests that only one correct response can be made to these design problems. In these design problems there are no correct or incorrect answers, because only you can tell us what the correct answer should be. For this reason it is most important that, although we cannot completely provide all the conditions under which you ordinarily design, you respond to these problems in the way in which you would ordinarily solve an actual design problem. Remember that the value of the information you provide depends on how accurately it reflects the way you ordinarily design on the job. Remember also that this is not a test of your ability, although we want you to do your best. We would not have selected you to do this work if we did not think you could do it.

We will probably meet once a week and the schedule will be adapted to your convenience. Between our sessions you may, if you wish, refer to the inputs you have been given. However, this part of the study is purely voluntary. During your sessions and in the interim, you may consult anyone inplant from whom you wish additional information. We do ask one thing of you, however; do not confer with your fellow participants in the study on any aspect of the study. To do so would seriously reduce the value of the results.

Are there any questions?

Here is the Statement of Work which you as the project engineer for the AGM-X ground maintenance system will have to work to. We would like you to take it with you and to examine it carefully. Please bring it with you when you return for the first session.

STATEMENT OF WORK

AEROSPACE GROUND EQUIPMENT (ELECTRONICS) FOR MAINTENANCE OF THE AGM-X

1.0 PURPOSE AND SCOPE

1.1 Purpose

This statement of work (SOW) establishes the requirements for the conceptual design of the ground maintenance equipment for the AGM-X system, including any peculiar checkout, maintenance and test equipment required. The AGM-X system is a short range attack missile which consists of the AGM-X air to surface missiles including nuclear warheads, B-52G and H carrier aircraft avionics equipment (CAE), carriage/launching mechanisms, support and training equipment, facilities, data and personnel.

1.2 System Description

1.2.1 Mission

The operational mission for the AGM-X carrier/missile weapon system is oriented toward the strategic objectives of the nation's general nuclear war forces.

The details concerning the concept of weapon system deployment, system performance and capabilities, and program scheduling, are classified.

1.2.2 Carrier Aircraft

The B-52G&H aircraft can carry eight missiles internally on a rotary launcher with four MK-28 bombs in the bomb bay, and 12 missiles externally (six per pylon). Carrier avionics incude the bombing navigation equipment, an inertial measurement unit, a master computer, the radiating site target acquisition system (RASTAS), and controls and displays necessary for the operation, control and launch of the AGM-X missiles. (Location and descriptions of these equipments are provided in the Appendix.)

1.3 Scope

The contractor shall conduct feasibility or trade studies for the design of an electronics checkout subsystem required to perform a complete operational check of missile and CAE electrical systems,

77

including the maintenance functions of malfunction isolation, calibration and checkout of malfunctioning AGM-X missile system components and subassemblies. The MGE requirements presented herein are limited to electrical/electronic equipment necessary for indirect field site support of the various system checkout and launch functions performed by OGE.

1.3 Scope

The contractor shall conduct feasibility or trade studies for the design of an electronics checkout subsystem required to perform a complete operational check of missiles and related CAE systems, including the maintenance functions of test, malfunction isolation, calibration and checkout of malfunctioning AGM-X missile system components and subassemblies. Based upon these feasibility or trade studies, the contractor shall select, describe, and design the optimum system for satisfaction of system design goals.

The Maintenance Ground Equipment (MGE) requirements presented herein are limited to electrical/electronic equipment necessary for indirect field site support of the various system checkout functions.

1.3.1 Assumptions and Prerequisites

1.3.1.1 For AGM-X, the conventional three levels of maintenance will be used and will be compatible with existing maintenance procedures and facilities.

Organizational maintenance down to the lowest replaceable unit will be performed by teams and specialists on the flight line and in the hangar. Flight line functions include removal and replacement of carrier aircraft equipment, installation and removal of single missiles or launcher/missile packages, integrated checkout of carrier and missiles and installation/replacement/exchange of warhead. Organizational level functions in the hangar include missile checkout, removal and replacement of missile components, missile installation and removal from launcher, and installation/replacement of warhead. Missiles will be repaired by removal and replacement of modular units after testing with a fault locater. Missiles are removed from the operational cycle for test and checkout only after onboard carrier tests show a malfunction. Periodic maintenance consists of a pre-flight and post-flight inspection on the carrier and replacement of time change items such as missile battery and cartridge-activated devices.

1.3.1.3 Maintenance functions to be performed at the field site repair shop will include malfunction isolation, calibration and checkout required for the repair of faulted subassemblies which have been removed from airborne and ground systems for repair and calibration.

1.3.1.4 (Eliminated)

1.3.1.5 MGE shall be available for malfunction isolation, calibration and checkout in the field site repair shop.

1.3.1.6 Where required, calibration capabilities shall be specified for instruments and MGE.

1.3.1.7 Items of MGE shall be of such variety and sufficient quantity to perform the maintenance functions required to fault isolate and restore to operating condition, AGE and airborne items of electrical/electronic equipment which are designated field repairable.

1.3.1.8 Electrical/electronic MGE is required to provide a means for functionally verifying the signals from the missile/pylon/launcher interface to the CAE subsystems. The following capabilitites must be included in the MGE:

(a) Verify the programmed events in a predetermined chronological, timed sequence and supply the resulting signals to the umbilical interface.

(b) Verify the status of prerequisites to each event.

(c) Respond in a predetermined manner to hold and recycle functions.

(d) Verify correctly programmed stimulus signals and evaluation of vehicle responses during vehicle checkout.

(e) Verify correct evaluation of vehicle discrete and analog functions which are used to determine vehicle readiness status.

1.3.1.8.1 In addition to the MGE required to accomplish the above functions, a simulation device will be required which will allow CAE equipment to be functionally checked without missiles/launchers/pylons being present. This simulator shall have the capability of electrically simulating missiles, launcher, and/or pylon functions

1.3.2 Requirements

The contractor shall ensure that at a minimum the following aspects are considered in these trade studies:

(1) Cost (Hardware costs only)

(2) Equipment maintainability (see paragraph 8.0)

(3) Equipment reliability (see paragraph 7.0)

(4) Number and type of personnel required (see paragraph 5.0)

(5) Performance efficiency

(6) Safety

The trade studies will analyze three alternative equipment configurations: manual, semi-automated and automated, and document the reasons for selection of the contractor's chosen alternative.

2.0 Applicable Documents

General - The following documents form a part of this specification to the extent specified herein. In the event of conflict between the requirements of this specification and any document referenced herein, the requirements of this specification shall govern. References in the following documents will be considered only as a guide.

Technical Orders

T. O. 00-20K(series) - Inspection and AGE Control, USAF Equipment

Manuals

AFSCM 80-3 - Handbook of Instructions for Aerospace Personnel Subsystem Designers

AFSCM 80-6 - Handbook of Instructions for Aerospace Ground Equipment Designers

AFSCM 80-8 - Handbook of Instruction for Missile and Space Vehicle Design, Vol. 1 Ballistic Missiles

AFSCM 80-9 - Handbook of Instructions for Aerospace Systems Design, Vol. 1 General Design Criteria

AFSCM 127-1 - System Safety Management

AFSCM 375-5 - Systems Engineering Management Procedures

Specifications

Military

MIL-T-152B	Treatment,,Moisture - and Fungus-Resistant, of Communications, Electronic, and Associated Electrical Equipment
MIL-S-8512B	Support Equipment, Aeronautical, Special, General Specification for the Design of

	MIL-S-38130	Safety Engineering of Systems and Associated Subsystems, and Equipment, General Requirements for

Standards

Federal	FED-STD-595 1 Feb. 1961	Colors
Military	MIL-STD-143	Specifications and Standards, Order of Precedence for the Selection of
	MIL-STD-454A	Standard General Requirements for Electronic Equipment
	MIL-STD-808	Finishes, Protectives, and Codes, for Finishing Schemes for Ground and Ground Support Equipment
	MIL-STD-210M	Climatic Extremes for Military Equipment
	MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment and Facilities
	MIL-STD-470	Maintainability Program Requirements (for systems and equipments)

3.0 Engineering Inspections

3.1 Preliminary Design Review

The contractor shall conduct a preliminary design review not later than 60 days subsequent to award of the contract. This review shall be in accordance with AFSCM 375-5, and shall be subject to approval of the AGM-X Project Office.

3.2 Critical Design Review

The contractor shall conduct a critical design review 180 days after award of contract. This review shall be in accordance with AFSCM 375-5, and shall be subject to approval of the AGM-X Project Office.

3.3 Final Acceptance

Final acceptance of the contractor's work shall be indicated by accomplishment of a DD Form 250 reflecting the technical acceptance of the designs provided by the contractor and completion of all contractual requirements as specified in this SOW and associated documents. In the event there are exceptions to the acceptance reflected on the DD Form 250 or attachments thereto, the contractor shall be required to correct all exceptions as specified within the time limit mutually agreed upon during the execution of the DD Form 250.

4.0 Performance Requirements

4.1 Checkout and Test Equipment

Support of the missile and associated carrier aircraft system shall be accomplished through the use of checkout equipment which shall enable the operator to perform a gross operational performance analysis of the system. Test equipment shall be identified as that required to perform a more detailed analysis of the system down to the lowest level of replacement unit.

4.2 Checkout and Test Time

The time required to connect the checkout and test equipment to the missile and/or associated missile-carrier aircraft system, warmup, conduct the required tests, and disconnect the equipment shall be held to a minimum, and in no case (other than malfunction correction) shall exceed two hours. Lightweight cable assemblies and connectors, and quick disconnects, shall be used in order to facilitate ease of handling, connection and disconnection.

4.3 Degree of Testing

The test method utilized shall employ the minimum number of tests necessary to check out the missile and associated missile-carrier aircraft system or isolate a malfunction to the lowest replaceable unit (LRU).

4.4 Test Tolerances

The extent of test tolerances shall be limited to that necessary to establish realistic acceptance or rejection criteria for the missile and associated missile-carrier aircraft systems based on operational requirements. The major test tolerances shall further be predicated on the operational tolerances of the systems. The test equipment shall not be required to test to the design tolerances of the system, except in instances where design tolerances and operational tolerances are identical and/or can be obtained without additional penalty.

4.5 Communication

Equipment shall be provided for communication between personnel.

4.6 Interconnections and Cables

The contractor shall give consideration to the utilization of the interconnecting devices which are compatible with the missile, carrier-aircraft, and associated maintenance equipment. This will include electrical, hydraulic, and penumatic interconnections, as well as hitches, towbars and full servicing vehicle fittings. Interconnecting cables shall be provided as necessary to connect the test equipment to the missile/aircraft system, and to any portable antennas, etc., that are required for flight line maintenance. Cable lengths shall be sufficient to permit positioning the checkout equipment so as not to interface with normal missile/aircraft servicing during checkout of the system. Provisions shall be made for storing all interconnecting cables and other accessories within the checkout equipment.

4.7 AGE Size and Weight

The contractor shall give consideration to the design of AGE with regard to weight and size (reference MIL STD-1472). Checkout and test equipment should be transportable by the minimum number of personnel and should be capable of being carried aboard the aircraft through existing access doors.

4.8 AGE Maintenance

AGE shall be designed, wherever possible, to utilize non-repairable (throw-away) components to facilitate ease of maintenance and to minimize the requirement for detailed maintenance logistic considerations. The contractor shall give consideration to the maximum utilization of the modular concept in the design of AGE to facilitate fault isolation and maintenance repairs within the AGE.

4.9 Calibration

Electronic and electromechanical AGE shall be designed to permit calibration at specified intervals. Test points will be provided to permit calibration.

4.10 Flight Line Checkout and Test Equipment

The flight line checkout and test equipment shall provide the operator with the capability to analyze the functional performance of the system, subsystems, and components statically and/or dynamically with the optimum degree of accuracy in test results. Utilization of standard and commercial equipment is encouraged. Checkout and test equipment shall perform integrated system tests where integrated airborne systems are utilized. Whenever a dynamic testing concept is employed, the AGE shall be capable of presenting test problems representative of those encountered by the systems in operation in order to determine the system performance level under normal environment. Testing, whether static or dynamic shall be sufficiently comprehensive to analyze and isolate to the LRU level, in the optimum period of time, the functional performance of the airborne systems. Testing and monitoring displays shall be so designed as to minimize interpretation by operators.

4.11 Electronic Electrical AGE

Flight line electrical/electronic AGE will be designed to perform the following:

(1) Verification of hazardous current safety when electrically mating the missile or launcher/missiles to the carrier-installed system.

(2) Insertion and verification of mission data into the carrier master computer prior to committing an aircraft to alert.

(3) Simulation of missile or missiles/launcher to permit integrated test of carrier CAE prior to actual installation of the missile or missiles/launcher.

(4) Verification of system integrity.

(5) Fault isolation to the Line Replaceable Unit level.

4.12 Shop Checkout and Test Equipment

The primary utilization of shop checkout and test equipment shall be that required for the more detailed analysis of systems, subsystems, and/or components that have been removed from the missile/carrier--aircraft after being diagnosed as malfunctioning and placed in the environment of the field shop. This type of AGE will enable the technician to test the airborne equipment to the lowest level of removable units with the maximum practical accuracy. Periodic maintenance and system overhaul shall also be performed with shop checkout/test equipment. This equipment shall provide the following:

(a) Performance of routine maintenance tests and complete functional tests of line rejected units.

(b) Detection and location of malfunctioning module assemblies of line rejected units.

(c) Facilities for the replacement, adjustment, calibration, and repair of defective line rejected units.

(d) A self-checking capability for use in checking the shop checkout and test equipment without the use of any ancillary test equipment.

4.13 Electrical Equipment

All electrical equipment shall conform to the general requirements of AFSCM 80-6 and specification MIL-S-8512 and shall be compatible with the aircraft and missile systems. Electrical power equipment designed for 400 cycles, 3 Phase, 208 VDC shall be compatible with the power characteristics defined in specification MIL-STD-704. Electrical systems designed for operations on 220V, 3 Phase, 60 Cycles, shall be readily convertible to 440V, 3 Phase, 60 Cycles, without replacing componenets.

5.0 Personnel Subsystem

5.1 Personnel Manning Requirements (for O-N Group)

Use of AGE for the maintenance and testing of any individual system, subsystem or component of the missile and associated missile-carrier aircraft shall not require more than two operators--one at or in the aircraft and one at the checkout or test equipment.

5.1 Personnel Manning Requirements (for O-S Group)

Equipment shall be designed to be operated by military technicians with an Air Force Speciality Code three-level skill only (see Appendix for definition of skill levels).

5.1 Personnel Manning Requirements (for Incremental Group)

Equipment Design shall minimize the quantity and skill level of military personnel required to operate the equipment.

5.2 Human Engineering

As outlined in MIL-STD-1472, the contractor will apply human engineering to hardware and system design to assure optimum operation and maintenance, utilization of the human as a component in the system, and reduction of tasks affected by human limitations to a minimum. This will include human design considerations for maintenance, operations, communications, illumination, noise level, reliability, safety, climate and environment (Ref. MIL-STD-1472). Studies and recommendations will be directed by AGM-X Project Office for the improvement of procedures and design as inefficient operations situations are detected.

6.0 Safety

All designs shall incorporate maximum protection for operating and maintenance personnel against hazardous conditions. Adequate provisions shall be made to warn and/or protect personnel and equipment against injury and damage. All designs shall be reviewed by qualified engineers.

7.0 Reliability

The AGE subsystem shall have a minimum mean-time-between-failure (MTBF) of 400 hours when operated under the environmental conditions specified in Table I. Failure is defined as the inability of the AGE subsystem to perform within the limits specified.

8.0 Maintainability

The contractor shall establish a maintainability program in accordance with applicable sections of MIL-STD-470 Maintainability Program Requirements. The terms and definitions for maintainability not otherwise described or delineated shall be in accordance with MIL-STD-778.

As a design goal, the MGE of AGM-X shall incorporate factors that enhance its ease of maintenance and accessability. The maintainability characteristics equipment, inspection, servicing, test, replacement and overhaul operations required to restore operational capability with a minimum expenditure of time, men and materials. When necessary to accomplish this requirement, special tools and service equipment shall be identified. The inclusion of maintainability characteristics as an inherent feature shall occur simultaneously with initial design and shall be continually analyzed and controlled throughout the development cycle. The equipment shall be designed so that the following system mean maintenance time shall not be exceeded:

Mean Corrective Maintenance Time (M_{ct}), 1.0 hour within 3.0 hours $= 1\sigma$.

TABLE XVII

ENVIRONMENTAL CONDITIONS

Environmental Conditions	Operation	Storage, Transportation, and Handling Limits
Low temperature	-65° minimum	-80°F (maximum duration 24 hours) followed and preceeded by equilibrium at -40°F
High temperature	125°F with a daily maximum of 160°F for 4 hours	+160°F for 4 hours daily
Temperature Shock	Not applicable	-80°F to +125°F within 5 minutes
Humidity	5% to 100% relative humidity with condensation at 85°F and below	Same as operation
Atmospheric pressure	15.4 psia to 7.1 psia	15.4 psia to 1.68 psia with maximum rate of descent of 5000 feet/min. and maximum rate of ascent of 2500 feet/min.

FURTHER REQUIREMENTS FOLLOW

The following material was appended to the statement of work. It was available to the Omnibus group as part of the basic SOW, and was provided as a separate input to the Incremental group in Session 3.

APPENDIX

The material provided in this Appendix contains information secured from design analyses performed by the Air Force. It presents information which the government feels will be useful in performing previously specified contractual activities. The Appendix is, however, to be viewed as being advisory only, and should not be considered as a contractual requirement.

DESCRIPTION OF THE AGM-X MAINTENANCE MAN

The System Specification establishes that airmen with certain basic skills and a specific level of proficiency must be able to operate and maintain the AGM-X weapon system. These airmen constitute a very critical element of the system. An understanding of this element of the Personnel Subsystem is essential to design of the AGM-X Weapon System.

To assist in defining what kind of individuals will be working with the weapon system, the following discussion describes the skill level codes used by the Air Force. Some historical information is also included.

Air Force career fields are identified by the first two numbers in the airman's Air Force Specialty Code (AFSC), such as 43XXX indicates Aircraft Mechanic, 46XXX indicates Weapons Mechanic. All officer specialties are explained in AFM 36-1 and all enlisted specialties are explained in AFM 39-1.

Possibly, the most significant position in the AFSC designation number is the fourth position, e.e., 46X3X or 31X5X. The fourth number establishes the skill level of the individual described by the AFSC. This skill designator is the key to designing a weapon system which can be maintained by the personnel spelled out. The skills assigned by the specification and described in AFM 39-1 are very broad in scope. Seldom do individuals qualify in all the required areas. Pressures of war, enlistment rate, etc., more frequently than not will cause downgrading of technical qualifications.

AIR FORCE MANNING - AUTHORIZED VS ACTUAL

The authorized numbers, and the skill level of the personnel to be assigned to a given AF unit, are indicated numerically as 3, 5, 7 and 9 level and can be translated as follows:

3 level - Helper/Apprentice
5 level - Specialist/Mechanic
7 level - Technician/Supervisor
9 level - Superintendent

A further translation is from indicated skill level to actual technical experience and is approximated as follows:

3 level - A basic AF technical school plus one year maintenance experience.

5 level - A basic AF technical school plus training on a specific weapons system plus one to five years overall experience.

7 level - Additional training and five or more years experience.

9 level - Additional training and 10 or more years experience.

After graduation from a basic technical course, the three-level airman will generally be assigned to work location at some operational base. His job assignments will be primarily removing and replacing components using technical manual procedures. The three-level airman is not permitted to deviate from procedures provided by technical manuals.

An airman with five-level skills has progressed through the three-level skill in the same or associated career field. He will have completed two to three years of work experience at the three-level and received some additional technical training and on-the-job training.

Most airmen holding a five-level skill have attended one additional technical school which was oriented to a specific weapons system. The training course was probably one to two months in length for electro/mechanical fields and two to five months for electronics, and provided specific information on operation, trouble analysis, checkout and repair of equipment for whcih he will be responsible. Experience in the five-level skill consists of trouble analysis, repair and checkout using voltmeters, electronic scopes, and tape programmed checkout equipment to take specific measurements. All activities of maintenance are directed by technical manuals, but, in some cases, may require use of basic theory for interpretation and analysis.

The five-level airman has been in the service three years, of which approximately 10 months were taken up in training. This leaves a 26-month period of time in which he could be considered actively engaged in his "trade." However, because of non-technical military activities and Air Force work load scheduling problems, the average direct labor manpower utilization rate is approximately 45%. When this 45% is factored into the 26 months not in training, the total experience gained in both the three-level and five-level skills is 11.7 months. In 84.6% of the cases, the airman is not highly motivated toward a military career and will take his discharge in one year.

An airman carrying seven-level skills is very likely to be a career airman. He has been in the service five years or more and holds the rank of S/Sgt. or T/Sgt.

PERSONNEL AVAILABILITY

The personnel to be available at the beginning of AGM-X training are anticipated to be from B-52 and B-58 units. The following personnel and related experience levels are anticipated:

Missile Electronic Maintenance Technician

31650/XX 1 year experience on a similar or related missile system

Munitions and Weapons Maintenance Technician

46250/XX 1 year experience on a similar or related missile system

PRELIMINARY QUANTITATIVE AND QUALITATIVE PERSONNEL REQUIREMENTS INFORMATION (QQPRI)

Analysis of the functional requirements of ground maintenance of the AGM-X system has resulted in the following preliminary descriptions of the personnel needed to perform ground maintenance.

The following Air Force Speciality Codes (AFSC) are required for performance of the integrated system checkout of the missile and carrier aircraft equipment.

The integrated checkout team will consist of the following AFSC's: 1515B, 31650/XX, 46250/XX.

1. 1515B. Operations Support Officer

The Operations Support Officer assigned to the Plans branch of the Wing Operations and Plans Division is responsible for developing the AGM-X mission plans from source data provided by higher headquarters. He is responsible for the loading of the mission tape data into the carrier aircraft master computers. He supervises the Missile System Analyst Specialist/Technician, AFSC 31650/70, in the operation of the data inserter monitor set (DIMS) during Mission data loading.

2. 31650/XX. Missile Systems Analyst Specialist/Technician

The Missile Systems Analyst Specialist/Technician is responsible for AGM-X maintenance activities at both the flight line and integrated maintenance facility.

At the flight line, he performs data loading into the carrier master computer using the operational, mission, and training tapes and the AGM-X data inserter monitor set. He performs integrated AVE/CAE tests on the AGM-X missile carrier aircraft systems. He performs scheduled inspections and organizational level maintenance of AGM-X missile launch control system and AGM-X carrier aircraft equipment.

In the integrated maintenance facility he prepares for and performs missile checkout and isolates missile malfunctions. He disassembles missile sections, removes and replaces faulty electronic components, and verifies repair. He tests, removes, replaces, and repairs faulty missile wiring. He removes and replaces the electronic and flight control sections during rocket motor replacement.

The Missile Systems Analyst Specialist/Technician performs bench testing of the AGM-X missile and carrier aircraft system components. He removes and replaces assemblies or subassemblies in the components and verifies component repair.

3. AFSC 46250/XX. Weapons Mechanic/Maintenance Supervisor

As a member of the AGM-X Weapons Loading Team, the Weapons Mechanic/ Maintenance Supervisor performs missile-to-carrier hazardous current checks and uploads and downloads the AGM-X missile, the launcher/missile package, the pylon/missile package, and bomb rack, in the B-52 aircraft. He performs/verifies ordnance and warhead safing and enabling during ground operations. He performs payload to missile hazardous current checks and installs/removes payload sections at the flight line. He observes and verifies launcher rotation during integrated system test. He transports the missiles, pylons, launchers, payload sections, and bomb racks to and from the flight line, integrated maintenance facility, missile/munitions storage facility or nuclear weapons storage facility, and empty pylons from the CAE/aircraft preflight maintenance facility to the integrated maintenance facility.

He performs organizational level maintenance on the launcher, pylons, bomb rack, AGM-X weapons status and control panel, and AGM-X consent panel in the aircraft. He performs organizational and field level maintenance on the munitions handling and transportation AGE.

SKILL LEVEL DEFINITIONS

The following is a definition of the Air Force skill levels referenced in this statement of work:

3 level --Usually acts as helper or assistant, but can do simple tasks on his own, such as simple checks. Performs simple manual operations readily (without assistance) but requires assistance (supervision or use of manuals) with more complex operations. The following activities are characteristic of the 3 level maintenance technician:

(1) Performs simple preventative maintenance without supervision;

(2) Performs emergency responses only when advised to do so by higher level technician;

(3) Removes and replaces modules under supervision;

(4) Performs potentially hazardous checks under supervision;

(5) Monitors and records equipment status values from displays;

(6) Performs programmed equipment checks in accordance with written procedures;

(7) Makes simple (discrete) electrical connections without supervision.

5 level --Performs most maintenance activities with the help of the 3-level. He may require assistance (supervision or use of a checklist) with more complex operations, particularly those requiring significant decisions or a high degree of hazard. The following is characteristic of the 5-level maintenance technician:

(1) Is capable of performing all activities of the 3 level technician;

(2) Performs potentially hazardous checks with minimal supervision;

(3) Removes and replaces modules without supervision;

(4) Decides what equipment checks should be made and when they should be taken;

(5) If test equipment malfunctions, corrects malfunction when crew chief not available;

(6) Assists crew chief in performance of complete subsystem checkout;

(7) Capable of performing most troubleshooting activities;

(8) Analyzes malfunction displays to diagnose equipment failures;

(9) Coordinates information from multiple displays to assess subsystem status;

(10) Supervises 3 level technician when crew chief not available.

7 level --Performs all tasks including those involving significant decisions and hazardous operations. The following activities are characteristic of the 7 level maintenance technician.

(1) Is capable of performing all activities of lower level technicians;

(2) Supervises lower level technicians and is responsible for all crew activities;

(3) Performs highly hazardous checks on own responsibility;

(4) Makes special purpose, elaborate electrical hookups;

(5) Takes responsibility for performance of complete subsystem checkout;

(6) Capable of performing all troubleshooting activities.

Figure 2. FIRST LEVEL FUNCTIONS

SEGMENT: FLIGHT LINE MAINTENANCE
(Provided to all groups as part of SOW)

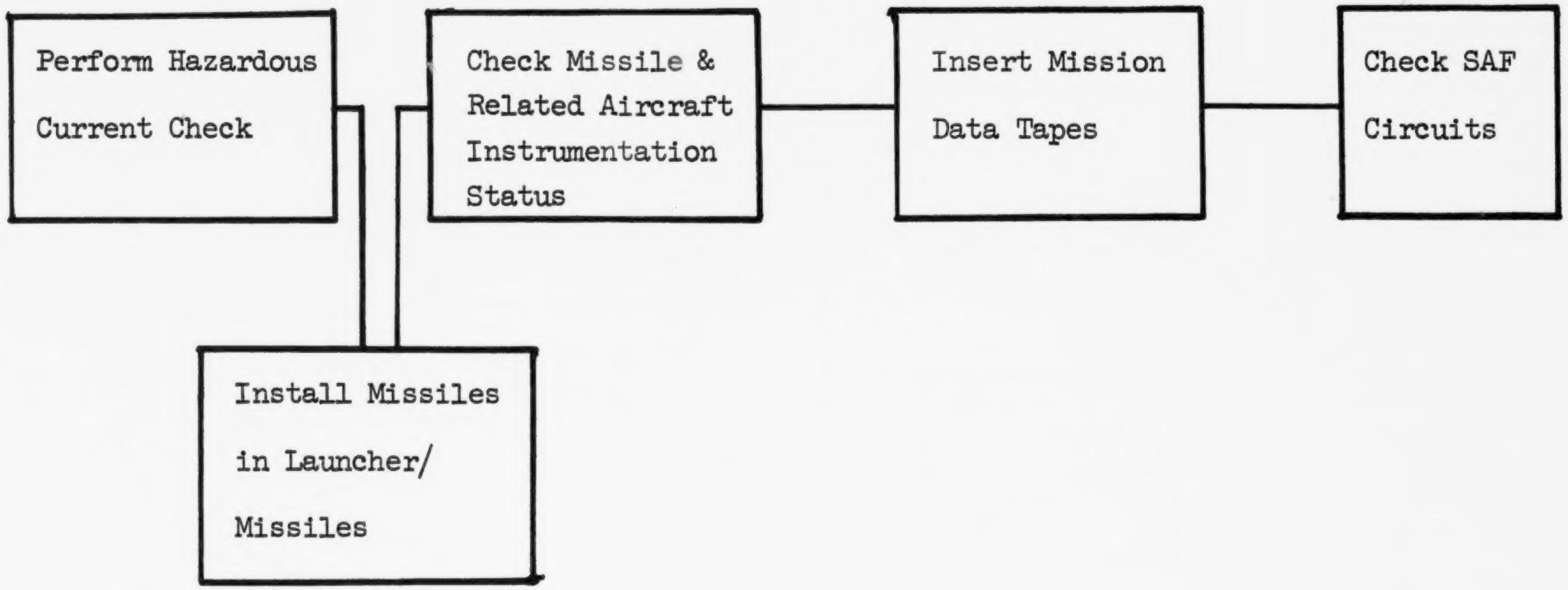
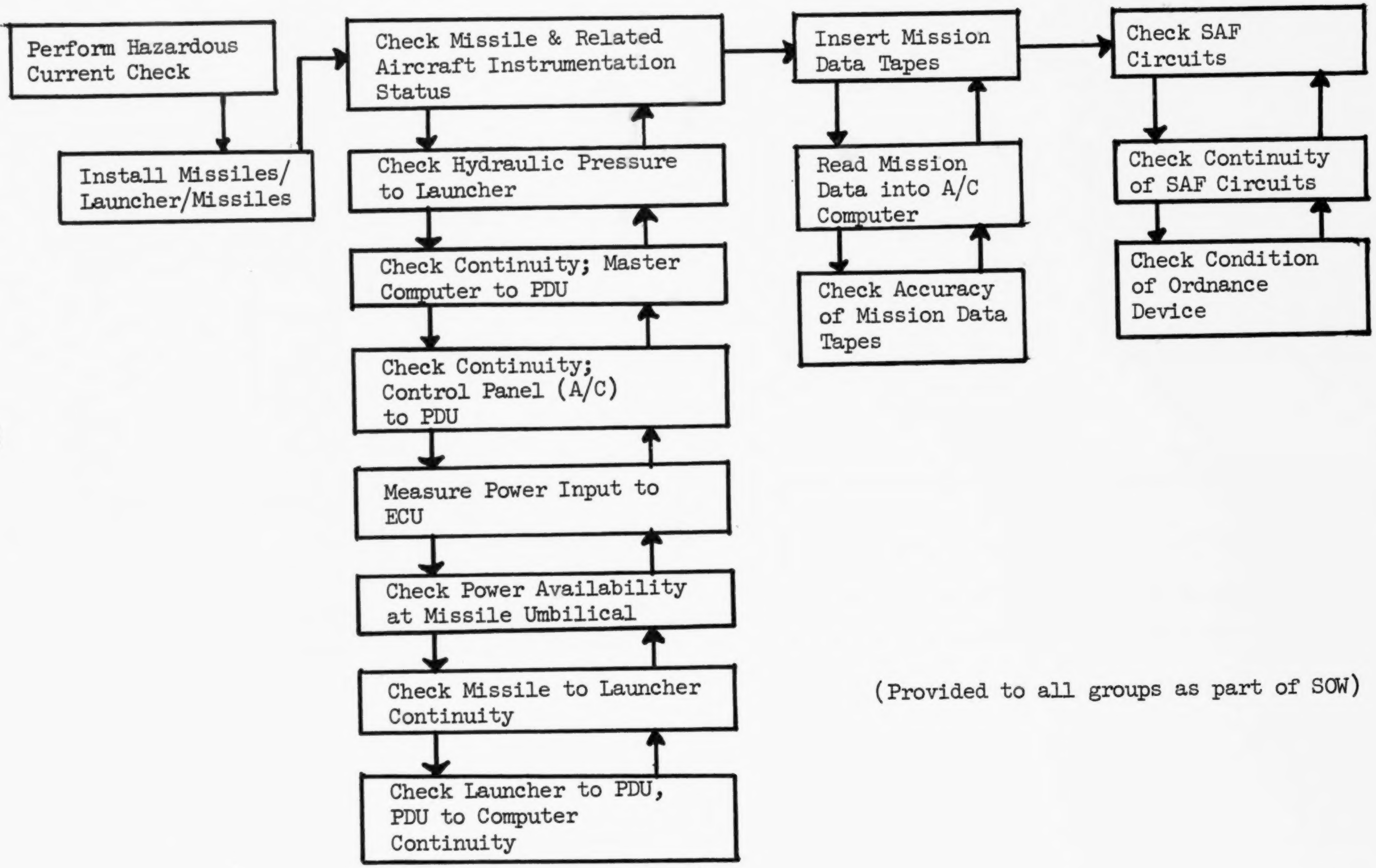

Perform Hazardous Current Check
Check Missile & Related Aircraft Instrumentation Status
Insert Mission Data Tapes
Check SAF Circuits
Install Missiles in Launcher/ Missiles

Figure 3. SECOND LEVEL FUNCTIONS

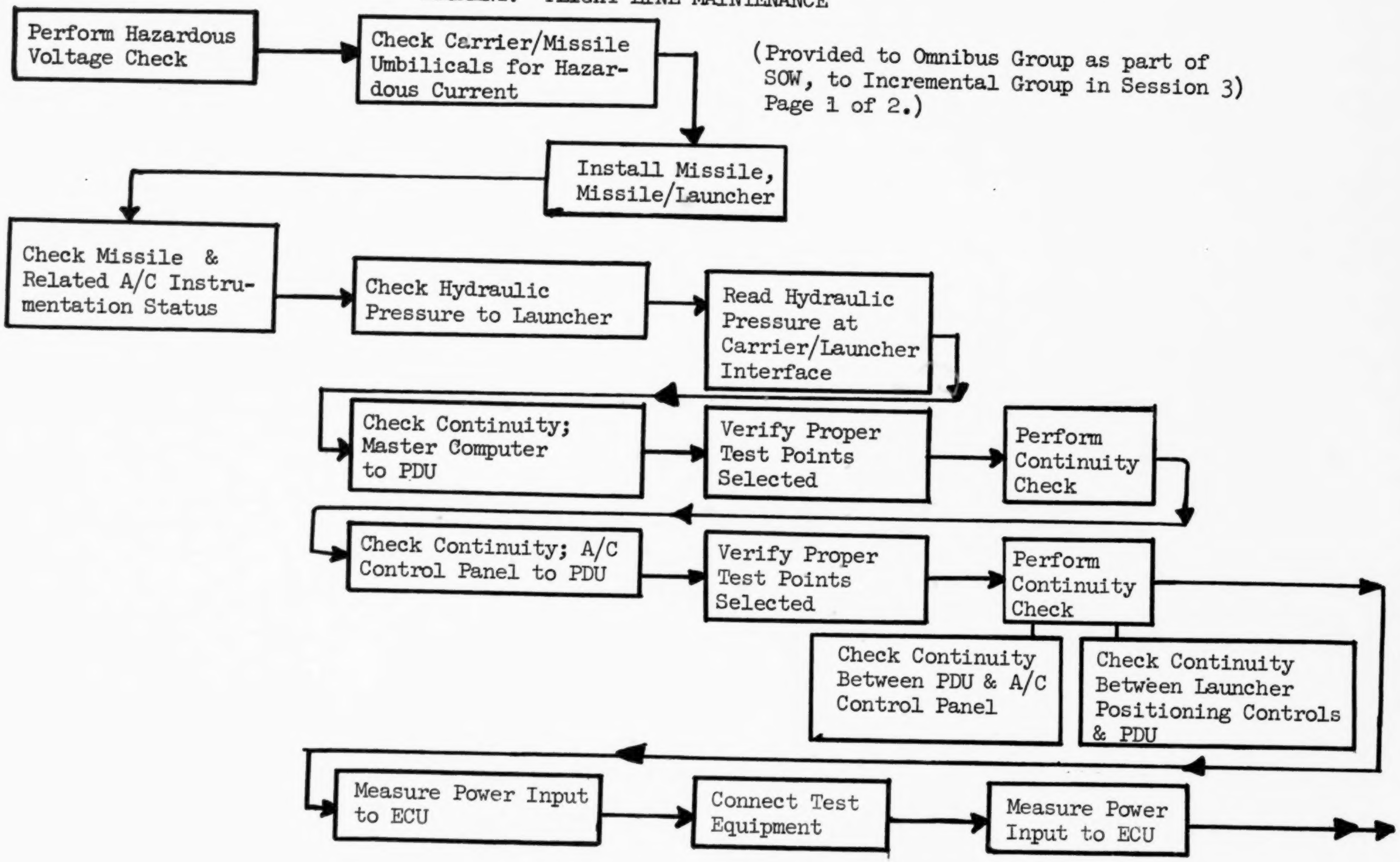
SEGMENT: FLIGHT LINE MAINTENANCE


Perform Hazardous Current Check
Install Missiles/ Launcher/Missiles
Check Missile & Related Aircraft Instrumentation Status
Check Hydraulic Pressure to Launcher
Check Continuity; Master Computer to PDU
Check Continuity; Control Panel (A/C) to PDU
Measure Power Input to ECU
Check Power Availability at Missile Umbilical
Check Missile to Launcher Continuity
Check Launcher to PDU, PDU to Computer Continuity
Insert Mission Data Tapes
Read Mission Data into A/C Computer
Check Accuracy of Mission Data Tapes
Check SAF Circuits
Check Continuity of SAF Circuits
Check Condition of Ordnance Device

(Provided to all groups as part of SOW)

Figure 4. THIRD LEVEL FUNCTIONS

SEGMENT: FLIGHT LINE MAINTENANCE


Perform Hazardous Voltage Check
Check Carrier/Missile Umbilicals for Hazardous Current
Install Missile, Missile/Launcher
Check Missile & Related A/C Instrumentation Status
Check Hydraulic Pressure to Launcher
Read Hydraulic Pressure at Carrier/Launcher Interface
Check Continuity; Master Computer to PDU
Verify Proper Test Points Selected
Perform Continuity Check
Check Continuity; A/C Control Panel to PDU
Verify Proper Test Points Selected
Perform Continuity Check
Check Continuity Between PDU & A/C Control Panel
Check Continuity Between Launcher Positioning Controls & PDU
Measure Power Input to ECU
Connect Test Equipment
Measure Power Input to ECU

(Provided to Omnibus Group as part of SOW, to Incremental Group in Session 3) Page 1 of 2.)

Figure 5. PERSONNEL FUNCTION FLOW DIAGRAMS

FLIGHT LINE MAINTENANCE

(Provided to Omnibus group as part of SOW, to Incremental group in session 3. Page 1 of 3)

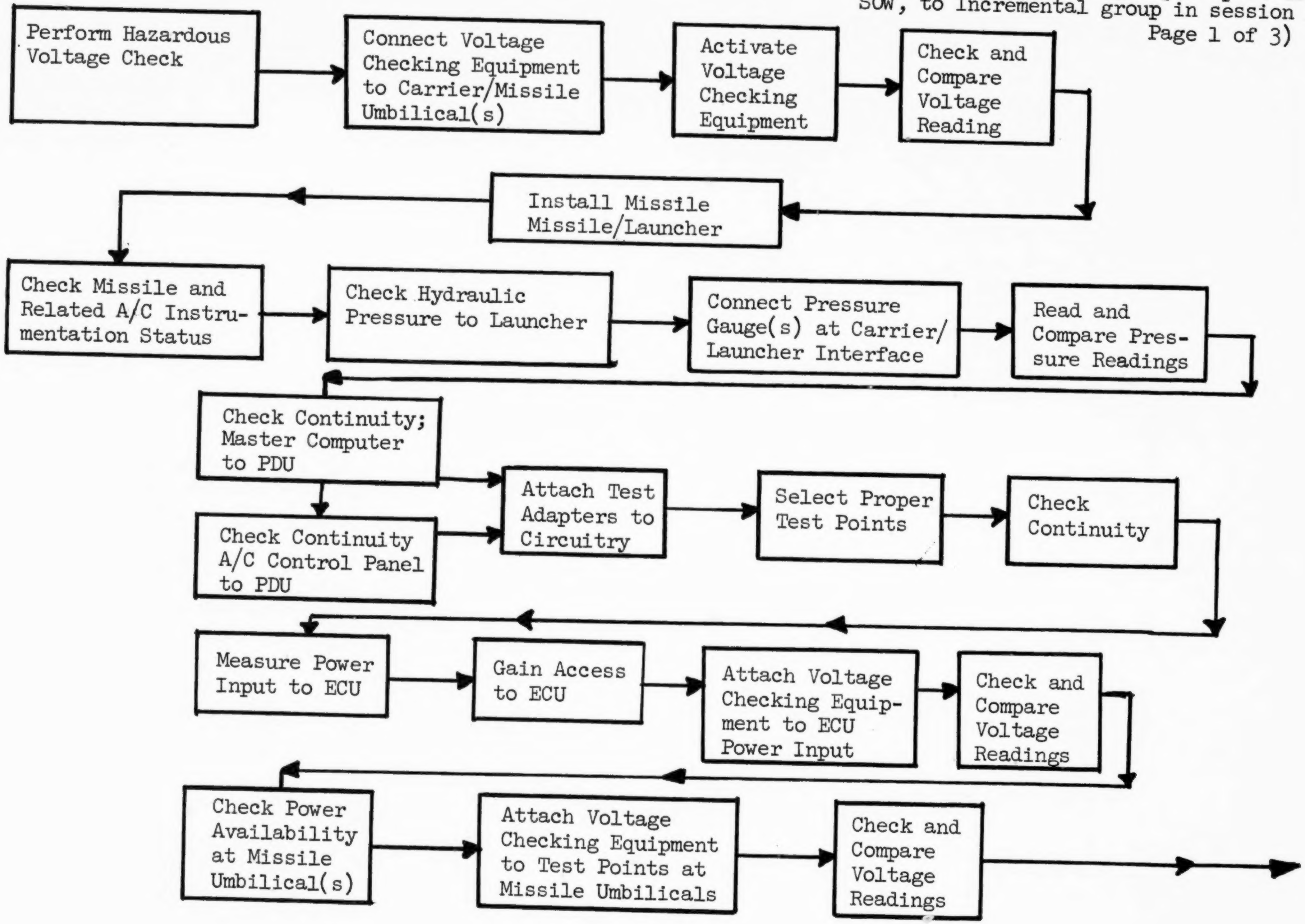

Perform Hazardous Voltage Check
Connect Voltage Checking Equipment to Carrier/Missile Umbilical(s)
Activate Voltage Checking Equipment
Check and Compare Voltage Reading
Install Missile Missile/Launcher
Check Missile and Related A/C Instrumentation Status
Check Hydraulic Pressure to Launcher
Connect Pressure Gauge(s) at Carrier/Launcher Interface
Read and Compare Pressure Readings
Check Continuity; Master Computer to PDU
Check Continuity A/C Control Panel to PDU
Attach Test Adapters to Circuitry
Select Proper Test Points
Check Continuity
Measure Power Input to ECU
Gain Access to ECU
Attach Voltage Checking Equipment to ECU Power Input
Check and Compare Voltage Readings
Check Power Availability at Missile Umbilical(s)
Attach Voltage Checking Equipment to Test Points at Missile Umbilicals
Check and Compare Voltage Readings

Figure 6. FIRST & SECOND LEVEL FUNCTIONS

SEGMENT: SHOP MAINTENANCE
(Provided to all groups as part of SOW)

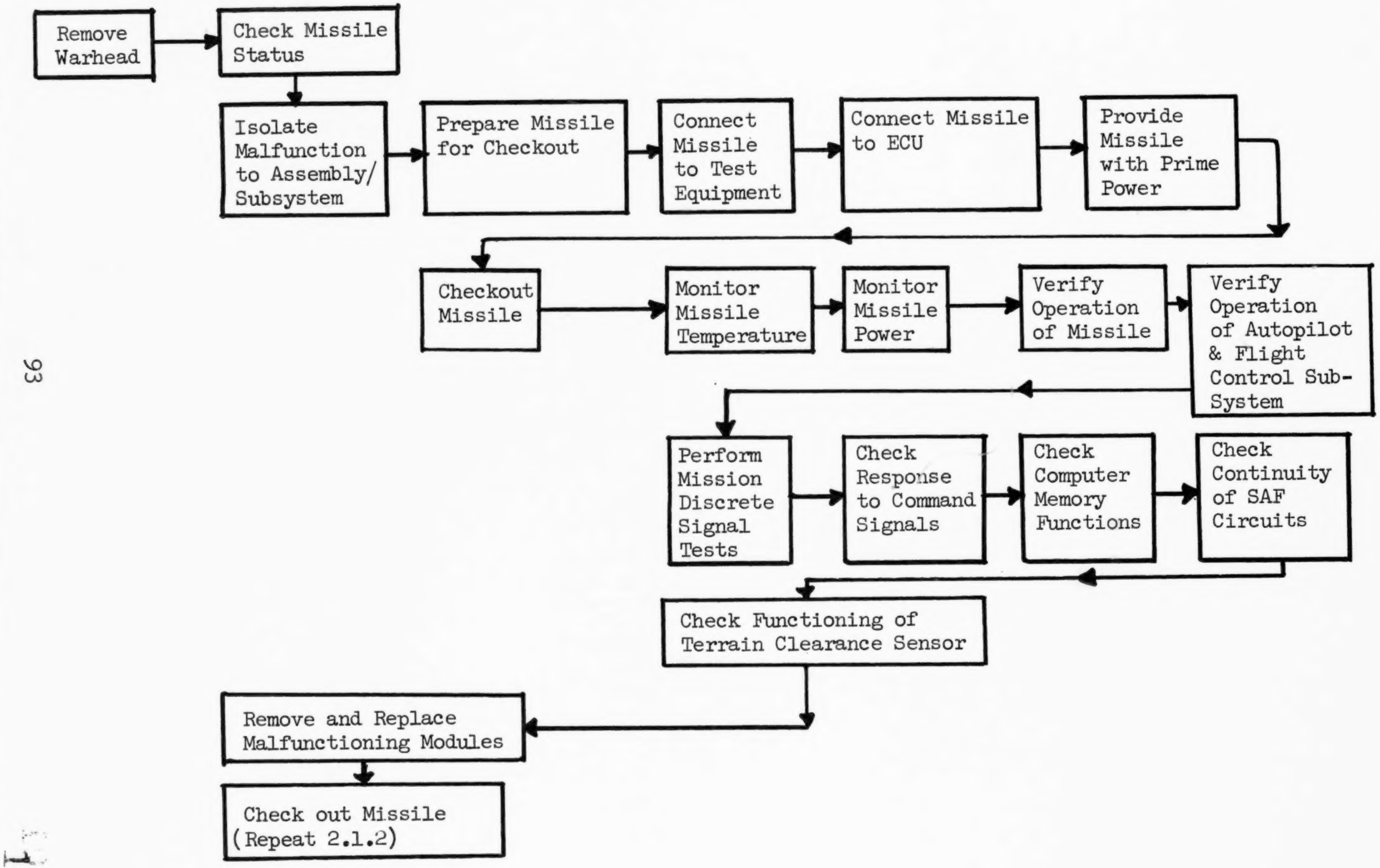
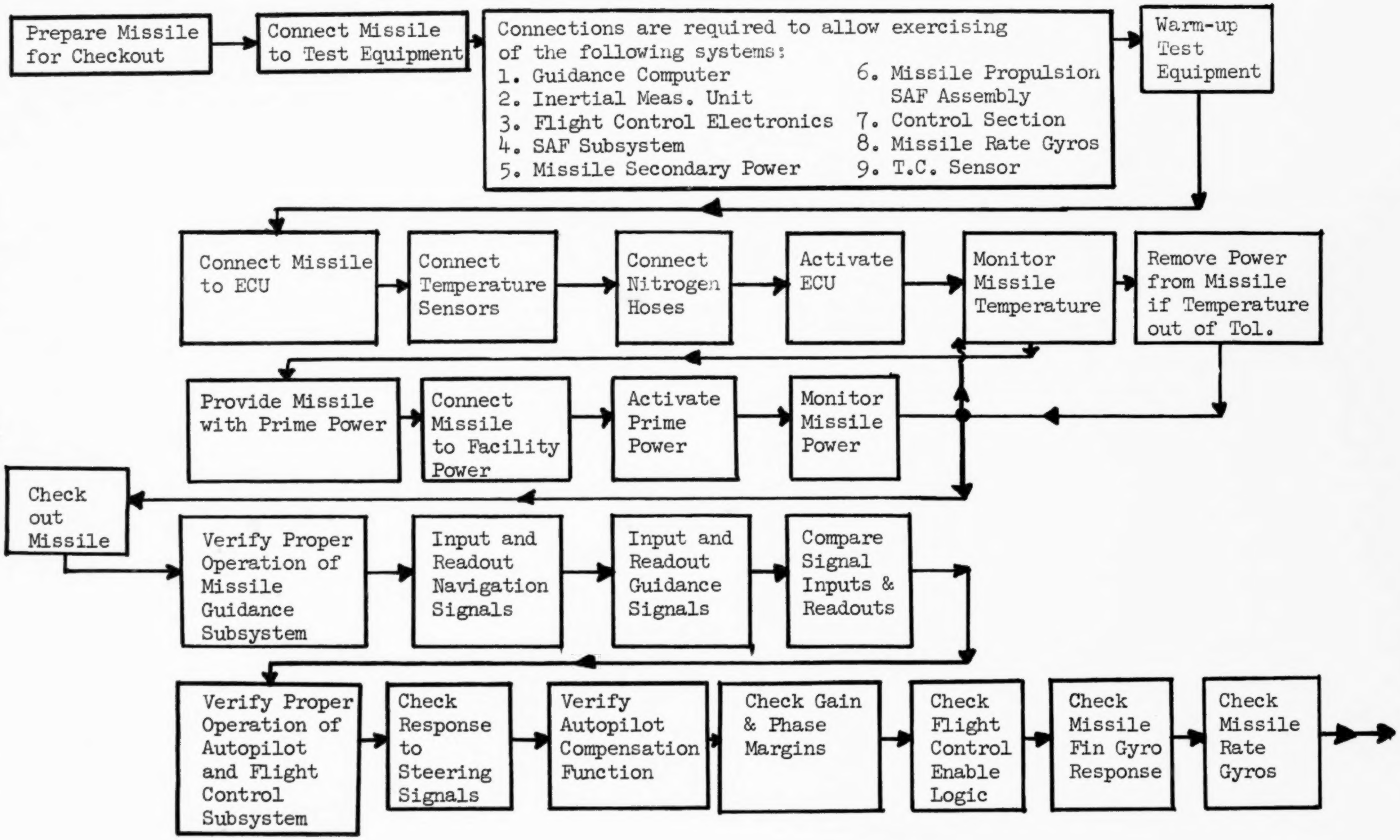

Remove Warhead
Check Missile Status
Isolate Malfunction to Assembly/ Subsystem
Prepare Missile for Checkout
Connect Missile to Test Equipment
Connect Missile to ECU
Provide Missile with Prime Power
Checkout Missile
Monitor Missile Temperature
Monitor Missile Power
Verify Operation of Missile
Verify Operation of Autopilot & Flight Control Sub-System
Perform Mission Discrete Signal Tests
Check Response to Command Signals
Check Computer Memory Functions
Check Continuity of SAF Circuits
Check Functioning of Terrain Clearance Sensor
Remove and Replace Malfunctioning Modules
Check out Missile (Repeat 2.1.2)

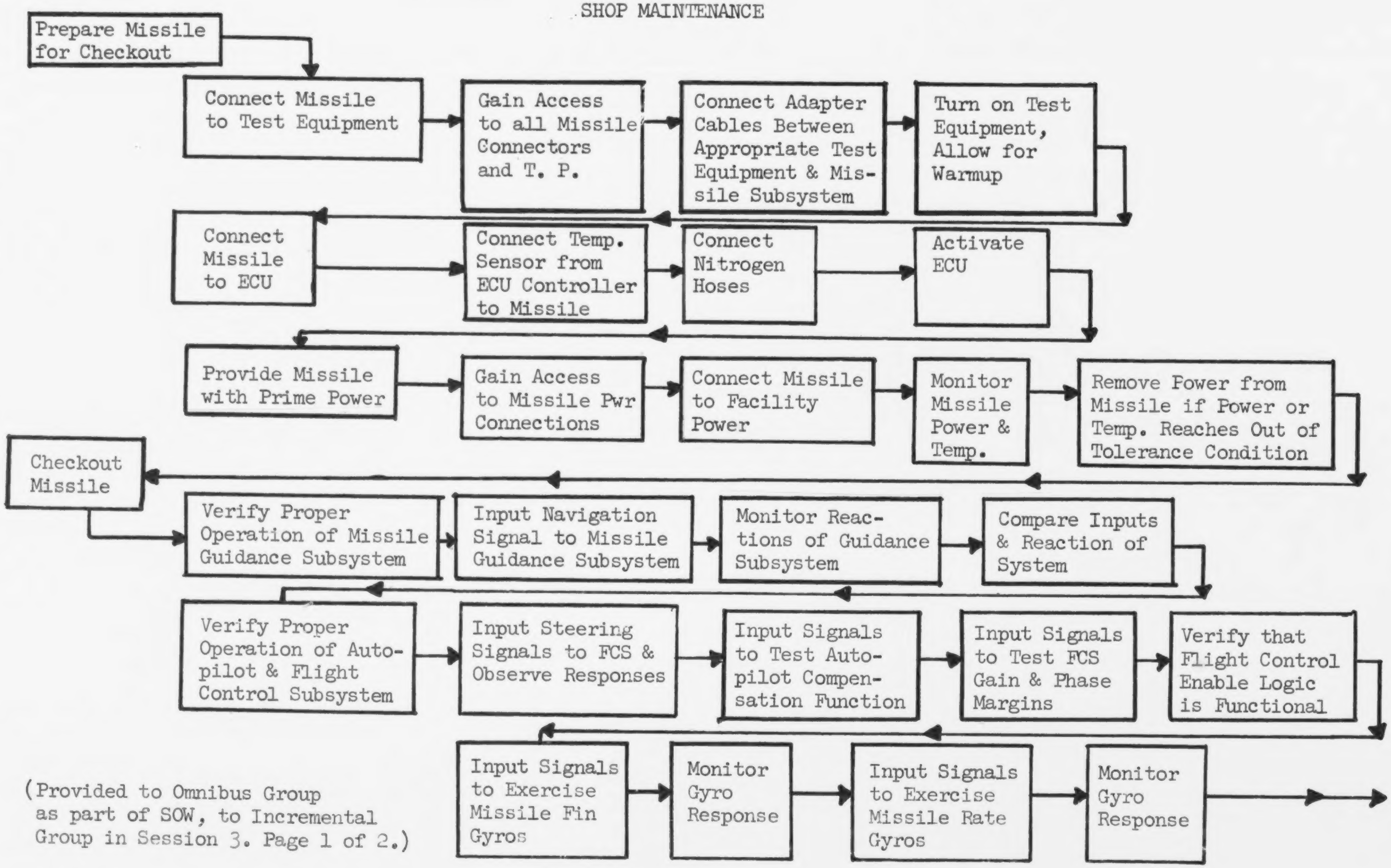
Figure 7. THIRD LEVEL FUNCTIONS
SEGMENT: SHOP MAINTENANCE


Prepare Missile for Checkout
Connect Missile to Test Equipment
Connections are required to allow exercising of the following systems:
1. Guidance Computer
2. Inertial Meas. Unit
3. Flight Control Electronics
4. SAF Subsystem
5. Missile Secondary Power
6. Missile Propulsion SAF Assembly
7. Control Section
8. Missile Rate Gyros
9. T.C. Sensor
Warm-up Test Equipment
Connect Missile to ECU
Connect Temperature Sensors
Connect Nitrogen Hoses
Activate ECU
Monitor Missile Temperature
Remove Power from Missile if Temperature out of Tol.
Provide Missile with Prime Power
Connect Missile to Facility Power
Activate Prime Power
Monitor Missile Power
Check out Missile
Verify Proper Operation of Missile Guidance Subsystem
Input and Readout Navigation Signals
Input and Readout Guidance Signals
Compare Signal Inputs & Readouts
Verify Proper Operation of Autopilot and Flight Control Subsystem
Check Response to Steering Signals
Verify Autopilot Compensation Function
Check Gain & Phase Margins
Check Flight Control Enable Logic
Check Missile Fin Gyro Response
Check Missile Rate Gyros

(Provided to Omnibus group as part of SOW, to Incremental group in Session 3. Page 1 of 2.)

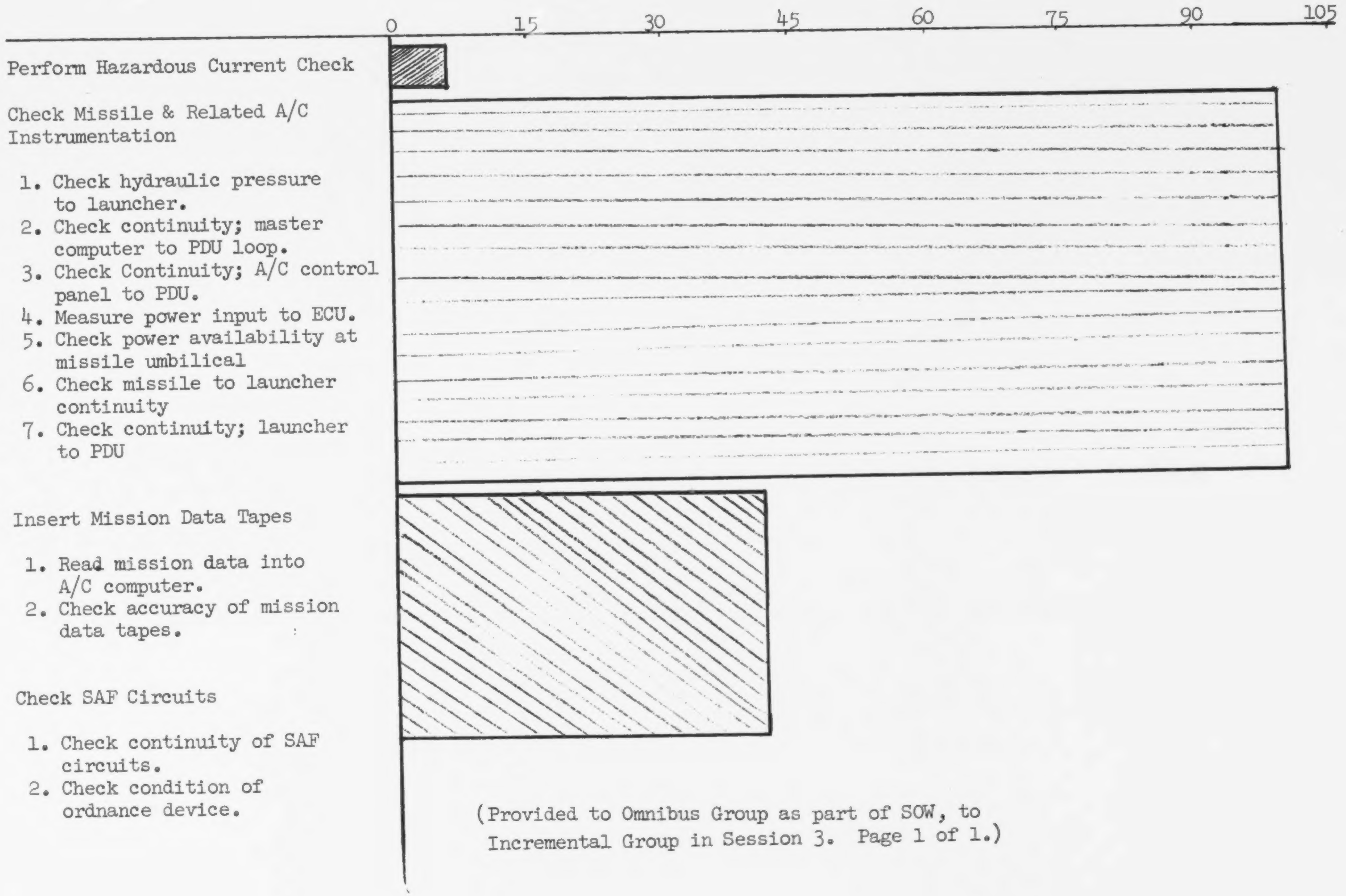
Figure 8. PERSONAL FUNCTION FLOW

SHOP MAINTENANCE


Prepare Missile for Checkout
Connect Missile to Test Equipment
Gain Access to all Missile Connectors and T. P.
Connect Adapter Cables Between Appropriate Test Equipment & Missile Subsystem
Turn on Test Equipment, Allow for Warmup
Connect Missile to ECU
Connect Temp. Sensor from ECU Controller to Missile
Connect Nitrogen Hoses
Activate ECU
Provide Missile with Prime Power
Gain Access to Missile Pwr Connections
Connect Missile to Facility Power
Monitor Missile Power & Temp.
Remove Power from Missile if Power or Temp. Reaches Out of Tolerance Condition
Checkout Missile
Verify Proper Operation of Missile Guidance Subsystem
Input Navigation Signal to Missile Guidance Subsystem
Monitor Reactions of Guidance Subsystem
Compare Inputs & Reaction of System
Verify Proper Operation of Autopilot & Flight Control Subsystem
Input Steering Signals to FCS & Observe Responses
Input Signals to Test Autopilot Compensation Function
Input Signals to Test FCS Gain & Phase Margins
Verify that Flight Control Enable Logic is Functional
Input Signals to Exercise Missile Fin Gyros
Monitor Gyro Response
Input Signals to Exercise Missile Rate Gyros
Monitor Gyro Response

(Provided to Omnibus Group as part of SOW, to Incremental Group in Session 3. Page 1 of 2.)

Figure 9. TIME LINE ANALYSIS
FLIGHT LINE MAINTENANCE



Perform Hazardous Current Check

Check Missile & Related A/C Instrumentation

1. Check hydraulic pressure to launcher.
2. Check continuity; master computer to PDU loop.
3. Check Continuity; A/C control panel to PDU.
4. Measure power input to ECU.
5. Check power availability at missile umbilical
6. Check missile to launcher continuity
7. Check continuity; launcher to PDU

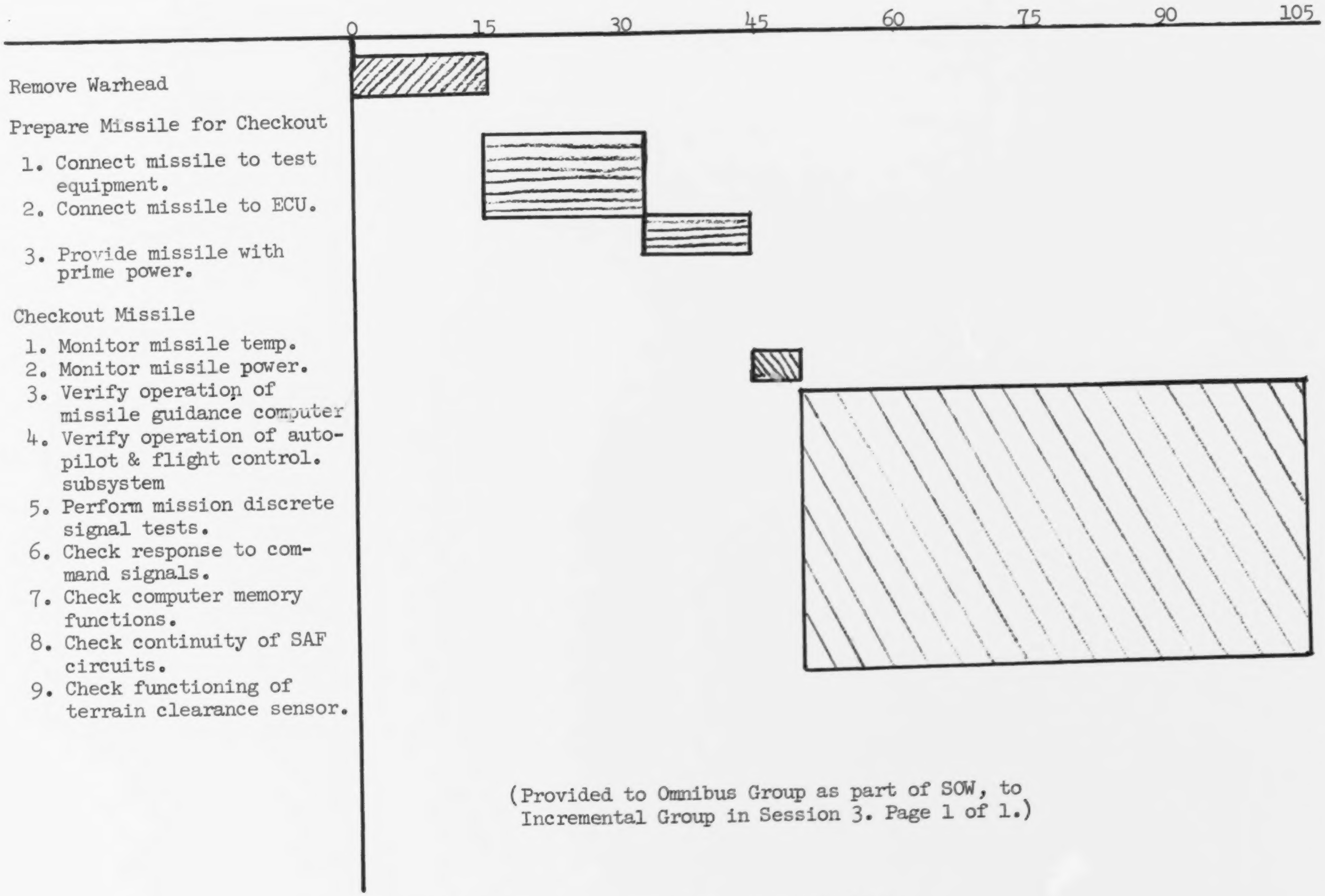
Insert Mission Data Tapes

1. Read mission data into A/C computer.
2. Check accuracy of mission data tapes.

Check SAF Circuits

1. Check continuity of SAF circuits.
2. Check condition of ordnance device.

(Provided to Omnibus Group as part of SOW, to Incremental Group in Session 3. Page 1 of 1.)



(Provided to Omnibus Group as part of SOW, to Incremental Group in Session 3. Page 1 of 1.)

Figure 10. Time Line Analysis: Shop Maintenance

Figure 11. Task Analysis

FLIGHT LINE MAINTENANCE

PERSONNEL TASKS	TIME	PERFORMANCE REQUIREMENTS	PERFORMANCE PROBABILITY	DIFFICULTY INDEX
1. Perform Hazardous Voltage Check	10	1.1 Connect GFE Hazardous Voltage Detector to the carrier/missile umbilical and to each of the critical missile components in turn - Requires knowledge of location of missile components. 1.2 Activate voltage detector - simple manual operation. 1.3 Read and compare voltage readings to system tolerances - regardless of type of system, this is essentially a simple manual task with no high skill demands.		
(INSTALL MISSILE, MISSILE/LAUNCHER) or (Connect Simulator to A/C)	10			
2. Check Missile and related A/C equipment status.	60			
2.1 Check hydraulic pressure to Launcher.		2.1.1 Connect Hydraulic Pressure Gauge(s to test pts. at the Launcher or Missile to A/C interface - simple manual task; requires knowledge of test point location. 2.1.2 Read pressure(s) and check against system tolerances - a simple manual task requiring knowledge of the functions of the hydraulic pressure should be.		

PERSONNEL TASKS	TIME	PERFORMANCE REQUIREMENTS	PERFORMANCE PROBABILITY	DIFFICULTY INDEX
2.2 Check continuity between the A/C Master Computer and the PDU		2.2.1 Attach adapter cabling to the Master Computer and PDU test points - simple manual task.		
		2.2.2 Set test equipment to perform continuity check.		
		2.2.3 Check continuity - A relatively simple task, but one which requires at least two men, one in the forward wheel well to make the connections and another at the test equipment.		
2.3 Check continuity between A/C control panels and the PDU.		2.3.1 Attach adapter cabling to PDU - simple manual task.		
		2.3.2 Activate each A/C control panel in turn and check continuity at the PDU - Task requires personnel inside the aircraft to activate the control panels and outside aircraft, operating the test equipment. Communication will be required among these technicians - requires knowledge of system tolerance values.		
2.4 Measure Power Input to ECU.		2.4.1 Attach adapter cabling from ECU in front wheel well to test equipment - simple manual task.		
		2.4.2 Set test equipment to measure approximate voltage range - knowledge of voltage range.		
		2.4.3 Read Input voltage and compare with system requirements - Task will require personnel in the wheel well and at the test equipment.		

PERSONNEL TASKS	TIME	PERFORMANCE REQUIREMENTS	PERFORMANCE PROBABILITY	DIFFICULTY INDEX
		Task is relatively simple, but does require knowledge of system tolerances and out-of-tolerance values.		
2.5 Check Power availability at Missile Umbilicals.		2.5.1 Attach adapter cabling to each missile umbilical in turn - simple manual task.		
		2.5.2 Set test equipment to measure approximate voltage range - simple manual task but requires knowledge of system values.		
		2.5.3 Read Input voltage and compare with system requirements - Task is relatively simple, but does require knowledge of system requirements and power measurement.		
2.6 Check Missile to Launcher continuity.		2.6.1 Attach adapter cable(s) at Missile/Launcher umbilicals - simple manual task.		
		2.6.2 Set test equipment to measure continuity - simple manual task.		
		2.6.3 Measure continuity, repeat for every missile - simple manual task, but may require several technicians to perform within required time limits.		
2.7 Check PDU Loops for continuity		2.7.1 Attach adapter cables from PDU to the test equipment - simple manual task.		
		2.7.2 Repeat 2.6.2.		
		2.7.3 Check continuity of all PDU loops - task is simple and could be performed by a single individual but		

PERSONNEL TASKS	TIME	PERFORMANCE REQUIREMENTS	PERFORMANCE PROBABILITY	DIFFICULTY INDEX
		may require several personnel to perform within required time limits. (8 additional pages of task analysis were provided.)		

Figure 12. REQUIREMENTS ALLOCATION SHEET

FUNCTION NAME	DESIGN REQUIREMENTS
PREPARE CARRIER FOR MISSILE(S) LOADING	1. (U) Prior to loading missile(s) and/or launchers onto the carrier, it is required that a hazardous current check be made of the CAE.
	2. (U) An adapter is required to provide an electro-mechanical interface between the hazardous current checker and the side of the missile. Necessary switching is required in that adapter to permit the hazardous current checks.
TEST LINE ITEM 1	3. (U) An integrated AVE-CAE test will be run on the carrier-installed systems prior to committing it to ready alert status. This same integrated test will also be run on carrier-installed CAE with a simulator replacing the launcher/missiles assembly. This test, in conjunction with certain additional fault isolation procedures, will establish the GO - NO GO status of each missile, the rotary launcher, and line-replaceable CAE.
PERFORM ORGANIZATIONAL MAINTENANCE	4. a. (U) Test equipment shall be identified as that required to fault isolate the system to the lowest level of base replaceable unit. b. (U) The test method used shall employ the minimum number of tests necessary to checkout the missile and associated missile-carrier aircraft system or locate a defective replaceable unit.
	5. a. (U) The time required to connect the checkout and test equipment to the AGM-X System or Subsystem, to warmup, to conduct the required tests, and to disconnect the AGE shall be held to a minimum. This time shall be compatible with the specified aircraft turn-around time. b. (U) To facilitate ease of handling, connection, and disconnection of the AGE, light-weight cable assemblies and connectors shall be used.
	6. (U) The test tolerance within which the AGE checks and tests the missile and associated missile-carrier aircraft systems, shall be based on the operational tolerances of the system.
	7. (U) Equipment shall be provided for verbal communication between operators.
	8. (U) Transportable checkout and test equipment shall be of a size and weight to allow handling by as few men as possible and to allow carrying aboard the aircraft through the normal access doors.

REQUIREMENTS ALLOCATION SHEET

FUNCTION NAME	DESIGN REQUIREMENTS
PERFORM ORGANIZATIONAL MAINTENANCE	9. (U) AGE shall make maximum use of non-repairable (throw away) modules and components to facilitate ease of maintenance and to minimize the requirement for detailed maintenance logistic considerations.
	10. (U) All electronic and electro-mechanical and electro-pneumatic AGE shall be subjected to a calibration process at such intervals as will be commensurate with the functional requirement of the equipment.
	11. a. (U) All electrical equipment shall conform to the general requirements of AFSCM 80-6 and Specification MIL-S-8512 and shall be compatible with the aircraft and missile systems. b. (U) Electrical power equipment designed for 400 cycles and 28 VDC shall be compatible with the power characteristics defined in Specification MIL-STD-704. c. (U) Electrical systems designed for operations on 220V, 3 Phase, 60 cycles shall be readily convertible to 440V, 3 Phase, 60 cycles without replacing components.
	12. (U) The mean corrective maintenance time for the AGM-X missile shall not exceed ________ minutes.
	13. (U) A positive means shall be provided to assure that the missile is in a "safe" condition prior to maintenance operations such as missile or missile rack unloading, missile or missile rack transporting, or missile checkout. The missile shall remain in a "safe" condition during these operations. Safe - All missile ordnance devices shall be mechanically and electrically in safed condition.
CHECKOUT AGM-X CAE	14. (U) A requirement exists to have the capability to perform an AGM-X CAE checkout without missiles aboard.
	15. (U) The CAE checkout shall: a. Verify a suspected malfunction, and b. Verify a replacement or repair of CAE installed in the carrier.
	16. (U) The CAE checkout shall verify the following components: a. Master Computer, b. Inertial Measurement Unit, c. Display and Control Panels, d. Processor & Distribution Unit, e. ECU, f. Cabling

REQUIREMENTS ALLOCATION SHEET

FUNCTION NAME	DESIGN REQUIREMENTS
	17. (U) A means is required to electrically simulate a missile when no missiles are aboard the carrier. A means is required to electrically simulate the launcher/missile package when no launcher/missile package is installed on the carrier. The simulator must be functionally capable of: a. Receiving input data and supplying simulated output data. b. Receiving missile alignment commands and providing simulated alignment status. c. Providing simulated missile status information for verification at the carrier displays and carrier computer. d. Accepting and returning SAF discretes to the carrier. e. Monitoring carrier power and power control signals. f. Accepting missile release mechanism commands and return appropriate status responses. g. Electrically simulating rotary rack response to positioning signals.

SESSION 1

Instructions to Participating Engineers

Now that you've had a chance to go over the SOW, we want you to develop the basic design concept of a system which will meet the requirements specified in the SOW. Among these requirements, you will note, are those which refer to the number and type of personnel. We ask you, therefore, in developing your design to particularly keep in mind the requirement to design to minimize personnel needs.

In describing this design concept, you should include the following:

(1) The number and types of major equipment items you would need;
(2) What each equipment would test;
(3) The characteristics you would design into the equipment;
(4) The functions to be performed by the equipment:
(5) The functions to be performed by the maintenance technician;
(6) The sequencing of equipment and personnel functions (in the form of a flow diagram).

Since this is a trade study, we want you to describe the design concept for each of the alternative types of configurations, manual, semiautomatic, automatic. Be as comprehensive as you can be with the information you have. If you need extra time, you can continue your analysis at the next session.

To help you remember the information we want, here is a form (see Table XV) which may help you in writing your answers. If it will help to describe the systems you are designing, you may make sketches of your equipment on a separate sheet of paper. Remember, however, that highly detailed drawings are not required. The flow diagram of personnel/maintenance sequences will, of course, be on a separate sheet of paper. To sharpen your answers, indicate just how your basic design concept varies among the three configurations.

You may ask any questions you wish at any time during the session, and I will answer it if I can.

At the conclusion of this session, ask the following:

1. Did you have enough information in the SOW to develop the design concepts?
2. Enough equipment information? Enough personnel information?
3. Is this equipment information characteristic of SOWs you work to?
4. Is this personnel information characteristic of SOWs you work to?
5. What information that you did not have would you wish to have?
6. Was the information in the SOW useful in helping you decide upon your system configurations? Has enough information been included in the personnel requirements statement? What design implications would you draw from the personnel requirements? (For omnibus group) From the personnel flow diagrams? Skill descriptions? From the QQPRI?
7. What information would you ordinarily have at the start of design?
8. What items of information in the SOW particularly affected your design decisions? Why?

9. What was the effect of the equipment requirements on your design?

10. What was the effect of personnel requirements on your design concept?

11. Is there any particular system configuration which you prefer? Why?

12. What are the major differences among the system types in terms of: reliability; maintainability; cost; number/type of personnel; design efficiency; safety?

13. For skill constraint group: predict the number of personnel you need for each configuration; why do you feel you need this number of personnel?

14. For number constraint group: tell me the personnel skill level you would need for each configuration; why do you need this skill level?

15. For incremental groups: tell me the number and personnel skill level you would need for each configuration; why?

INFORMATION REQUIRED	MANUAL	SEMI-AUTOMATIC	AUTOMATIC
No. and Type of Major Equipment Items			
Functions to be Performed by Equipment			
Functions to be Performed by Technician			
What Each Equipment Will Test			
Major Differences Among the System Configurations			

TABLE XVIII. Alternative System Configurations

SESSION 2

Instructions to Participating Engineers

In this session, we would like you to continue describing the various system configurations you began last time we met, but now in greater detail. If you have not already done so, please describe the functional characteristics of each major item of the maintenance ground equipment you think will be required.

In addition, we would like you to describe how the equipment you have designed would function in actual operations by listing in step-by-step fashion the procedures the maintenance personnel would perform in conducting -

(1) flight line maintenance checks;

(2) shop maintenance checks.

At the conclusion of the session, ask the following questions:

1. Has your design concept changed in any way from the preceding session?
2. If so, how? Why?
3. Did you have any difficulty in listing the operational procedure for your equipment? If so, why?
4. Was any of the information given you of any particular use in listing that procedure?
5. Have the equipment requirements acted in any way to constrain your design concept? If so, how?
6. Have the personnel requirements acted in any way to constrain your design concept? If so, how?

7. What equipment and personnel information which has not been provided to you would you wish to have? Why?
8. For skill constraint group: Predict the number of personnel you need for each configuration; why do you think you need this number?
9. For number constraint group: tell me the personnel skill level you would need for each configuration; why do you need this skill level?
10. For incremental groups: tell me the number and personnel skill level you would need for each configuration; why?
11. Is there any change in the system configuration which you prefer? If so, why?
12. In addition, please describe the personnel who will operate the maintenance equipment in terms of the skills which they must possess in order to handle each type of system.

SESSION 3 (Incremental Groups)

Instructions to Participating Engineers

In this session, we are able to provide you with additional information secured from the Air Force. This information describes the personnel requirements to which you should design; in addition, the Air Force has made a number of analyses, included in an Appendix to the SOW, which describe what they think the maintenance technicians in the system under design would be doing.

Please replace section 5.1 of your SOW which describes operator requirements with the following statement:

> (I-N Group) Use of AGE for the maintenance and testing of any individual system, subsystem, or component of the missile and associated missile-carrier aircraft shall not require more than two operators -- one at or in the aircraft and one at the checkout or test equipment.
>
> (I-S Group) Equipment shall be designed to operate by military technicians with a three-skill level only. (The definition of skill levels is included in the Appendix).

In this session, we ask you to review the design concepts you created previously in the light of the additional requirements and information now provided, and to make such changes as you feel would be necessary to bring your design in accord with the more stringent personnel requirements. Use a fresh copy of the same form you used previously to describe the changes you would make.

At the conclusion of the session, the following questions will be asked:

1. Did the additional information included in the Appendix to the SOW help you in modifying your design? If so, how?
2. What design implications would you infer from the personnel flow diagrams; QQPRI; skill level definitions, etc.? Are the skill level definitions understandable?
3. Do you ordinarily receive the kind of information contained in the Appendix?
4. Did the revised personnel requirements make any difference to your design? If so, what changes did you make?
5. What design implications would you draw from these requirements?
6. Are these requirements too stringent? Too easy?
7. (I - N group) What level of skilled personnel would you need to have to run your system under the personnel requirements imposed? Why?
8. (I - S group) What number of personnel would you need to have to run your system under the personnel requirements imposed? Why?
9. Of the three system configurations, which do you prefer? Why?

SESSION 3 (Omnibus Groups)

Instructions to Participating Engineers

At this time the Air Force customer has decided to make his personnel requirements a bit more stringent than they were when you started your design.

(O-N Group) If you look at section 5.1 of your SOW which describes operator requirements, you will see the following statement:

"Use of AGE for the maintenance and testing of any individual system, subsystem or component of the missile and associated missile-carrier aircraft shall not require more than two operators--one at or in the aircraft and one at the checkout or test equipment."

In order to minimize the skill level of the personnel needed to operate the maintenance ground equipment, the Air Force has levied the following additional requirement upon you:

"Equipment shall be designed to operate by military technicians with a three-skill level only." (Please refer to the definition of skill levels included in the Appendix to the SOW.)

(O-S Group) If you look at section 5.1 of your SOW which describes operator requirements, you will see the following statement:

"Equipment shall be designed to operate by military technicians with a three-skill level only."

In order to minimize the number of personnel needed to operate the maintenance ground equipment, the Air Force has levied the following additional requirement upon you:

"Use of AGE for the maintenance and testing of any individual system, subsystem or component of the missile and associated missile-carrier aircraft shall not require more than two operators--one at or in the aircraft and one at the checkout or test equipment."

In this session we ask you to review the design concepts you created previously in the light of the additional requirements imposed upon you, and to make such changes as you feel would be necessary to bring your design in accordance with the added personnel requirements. Use a fresh copy of the same form you used previously to describe the changes you would make.

At the conclusion of the session the following questions will be asked:

1. Did the additional personnel requirements make any difference to your design? If so, what changes did you make?
2. What design implications did you draw from the added personnel requirements?
3. Are these added requirements too stringent? Easy to handle?
4. Was there enough information provided in the added requirement?
5. What information would you wish included in the personnel requirements section of the SOW?

SESSION 4 (All Groups)

Instructions for Participating Engineers

Up to this point in time you have designed your systems to rather stringent personnel constraints. In this session we would like you to consider that all personnel constraints have been eliminated. In other words, consider that you are able to design for an unlimited number of personnel and any skill level which you think you might need. Please review your design concepts from this standpoint. In the event that you restricted your designs to fit the personnel constraints, indicate what changes in your designs you would wish to make, now that these restrictions have been voided.

(For incremental groups only: To help you in your design, additional information is now available from the Air Force describing its analyses of anticipated personnel characteristics and the tasks maintenance men would perform.)

Please complete a blank form such as you filled out previously, indicating the changes you would make in your designs with the personnel restrictions lifted. After you have done this, please compare the three system designs you have produced in terms of the following criteria:

(1) Effect on personnel; number; skill level;
(2) Cost;
(3) Reliability;
(4) Design adequacy;
(5) Maintainability.

After the engineer has completed this task, ask the following questions:

1. For incremental groups only: did the additional information provided by the Air Force help any? Did it affect your design solution in any way? If so, in what way? If not, why not?

The following questions are for all groups:

2. Did lifting the personnel restrictions influence you in any way in changing your designs? In what way? If not, why not?
3. We had made the assumption that the personnel requirements constrained your previous design in some ways. Is this true? How had these requirements affected your design?
4. Did your preferred design change any over the past four sessions when personnel requirements were changed? In what way? Why? If not, why not?
5. Do you feel that these personnel requirements are realistic? Unrealistic? Would you rather not be constrained in this way? Why not?
6. If you had to trade off personnel number and skill level, how would you do it? In other words, if you had a choice between a few skilled technicians or more unskilled personnel, which would you prefer? If you had more highly skilled technicians, could you use fewer people? If you had fewer people, would a higher skill level make up for the small size of the crew?
7. As far as your preferred design is concerned, which of the 5 criteria you used to compare the three systems would you consider to be the most important in determining your preference?

Note: The following equipment information will be provided only if subjects feel they require it.

Test Equipment

This part of the specification establishes the requirements for performance, design, test and qualification of the subsystem Test Equipment required to checkout missile electronics in the assembled missile and as separate subsystems. The test equipment shall provide power, stimuli and signal processing as required to checkout the AGM-X electronic subsystems.

Functional Characteristics. The Test Equipment shall provide power switching, safety monitoring, test stimuli and signal processing as required to test the AGM-X missile, missile electronic subassemblies and the AGM-X CAE electronic subassemblies. The Test Equipment shall have the capability of isolating faults in the AGM-X missile, missile electronic subassemblies and the CAE electronic subassemblies to the replacement level and of verifying the capabilities of the missile and subassemblies to perform within operational limits subsequent to repair.

Interface Requirements

Missile Electronics. The Test Equipment shall interface with the following AGM-X missile electronic units:

a. Master Computer
b. PDU
c. Multiplexer and Conversion unit
d. Control and Display panels.

Test Set, Environmental Control Unit

The primary purpose of the ECU Test Set is to functionally test the B-52 ECU (CAE). This is accomplished in conjunction with a GFP Blower and a GFE Nitrogen Filler System by monitoring the B-52 ECU output while providing a thermal load and pressure drop via the Test Set. Flex hoses direct the air flow between the Test Set and the ECU under test. There are two closed loops in the Test Set, one for the avionics circuits and one for the missile circuits. Circuits contained on the Test Set include temperature, pressure and flow gages and electrical heaters. 400H_z and 28VDC switching to the ECU under test is provided through the Test Set from facility power. The Test Set is used in the Integrated Maintenance Facility.

Performance

Functional Characteristics. The Test Set shall provide for checkout and fault isolation of the CAE, ECU when the CAE, ECU is in a non-installed condition.

Primary Performance Characteristics. The Test Set shall be capable of:

a. Simulating that portion of the cooling system (AGM-X missile and carrier aircraft avionics) which is not an integral part of the CAE, ECU.

b. Providing a heat load to the conditioning fluid of the CAE, ECU which is equivalent the maximum expected heat load of the AGM-X missile and carrier avionics.

c. Providing CAE, ECU monitoring capabilities that will indicate in tolerance operation or component fault.

Secondary Performance Characteristics. The test set shall be capable of:

a. Providing a visual indication of CAE, ECU conditioning fluid temperature, pressures and flows.

b. Monitoring the signal output from the CAE, ECU cooling effect detector.

Interface Requirements. The Test Set shall functionally interface with the following:

a. The conditioning fluid interface on the Environmental Control Unit, B-52/AGM-X (CAE).

(Additional material was provided when requested by subjects.)

APPENDIX II

TYPICAL DESIGN OUTPUTS

GME COMPATIBILITY AND IMPORTANCE CHART

GME REQD.	GME HARDWARE CAPABILITY Human Operator	Poor Access	Wide Environment	Highly Complex	Large No. Tests	Electric Air + LN_2	Prob large Power Req	Airborne Hardware Computer Controlled	Airborne Hardware Self Checks
* Portable Small	OK 1	OK 1	1	2	2	2	NO	3	NA
Calibratable *	OK 1	NA	2	1	NA	1	NA	NA	NA
High Reliability High MTBF *	2	NA	2	3	2	2	NA	2	2
Personnel Avail. Critical *	OK 3	NA	NA	3	3	NA	NA	3	NA
Personnel Training Limited *	NA	NA	NA	4	3	NA	NA	4	4
Fail Safe *	1	NA	1	1	1	1	1	NA	NA
Short Use Time *	2	2	NA	2	3	2	NA	3	2
TO AF Specs. *	1	1	1	1	1	1	1	1	1
Easily Maintained *	2	NA	NA	2	NA	2	NA	2	2
Easy to Understand *	OK	NA	NA	3	3	OK	OK	3	3

* In plane system. ** Ramp GME. *** Shop GME.

1-Required; 2-If Possible; 3-Compromise; 4-Impossible

Total Count 90 Manual
360 Full Automation Reqd
(Count 1 for NA)

Figure 13. Tradeoff Decision-Making Matrix

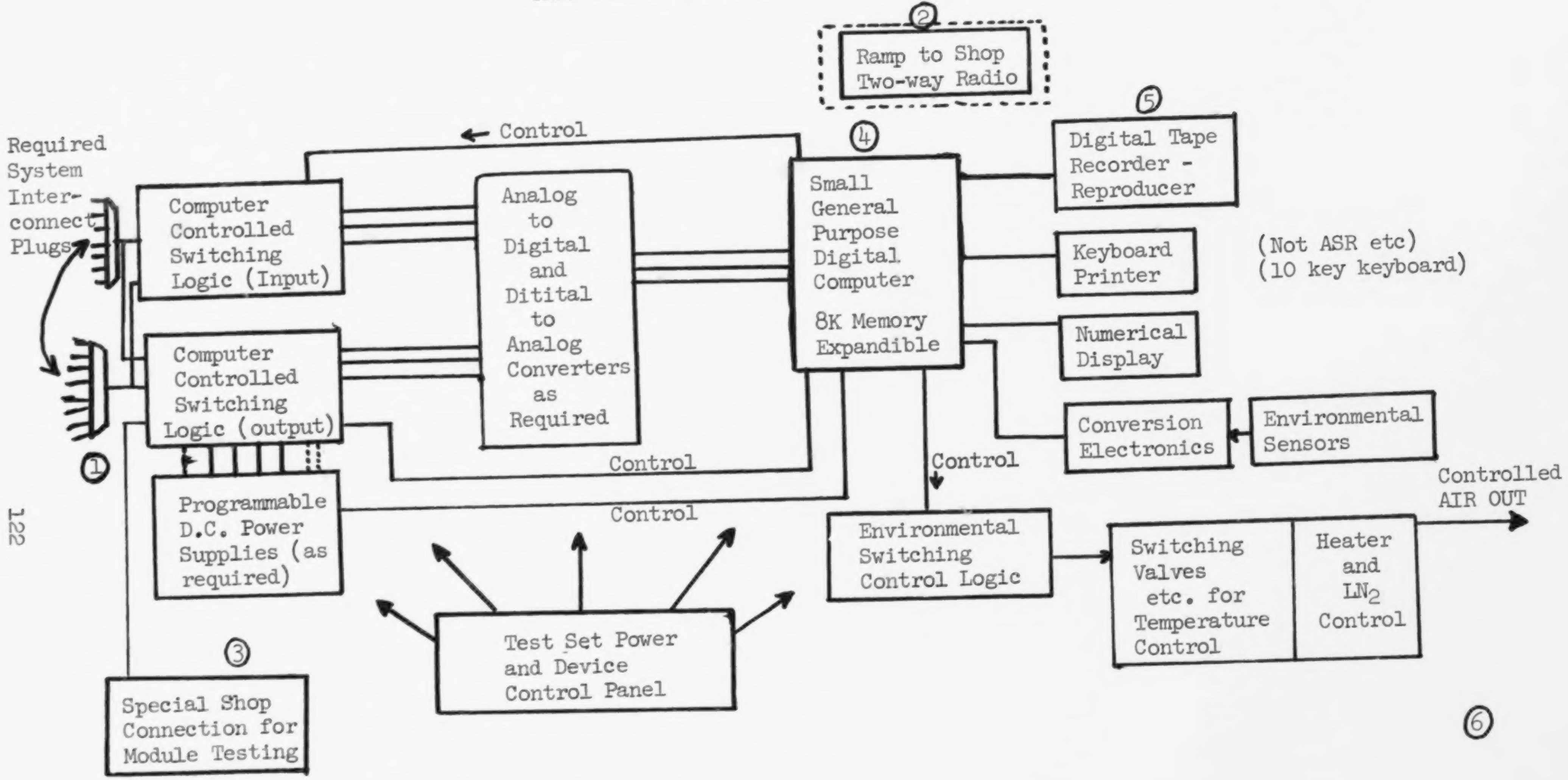
Figure 14. System Description

As fully automated a system as possible, containing:

- a computer to check out the missile and A/C computer
- would design flight test set to check to the module level and use it in the shop as well
- self-diagnostic capability
- 2 or 3 programmable power supplies (from digital word generates required signal only
- computer provides flexibility to test set, missing in hard-wired equipment
- reduce operators role as decision maker
- sufficient level of information must be provided to reduce boredom and keep operator on his toes without overwhelming him. Minimum number of displays (test No & Go-No Go)
- Provide test set with ability to lower or raise operational voltage levels to provide "marginal" checks of equipment.
- feedback to include test performed and results and would include a print-out record
- modular construction
- wheeled cart, to include all cables, etc.
- would include data inserter function
- minimum number of computer controls accessible to operator
- would incorporate location of fault information on printout
- could very well be used to checkout other systems
- checkout - approximately $1\frac{1}{2}$ hours.

Figure 15. Flow Diagram of System Inputs and Outputs

RAMP AND SHOP SYSTEM TEST SET (RASSTS)


②
Ramp to Shop Two-way Radio
⑤
④
← Control
Required System Interconnect Plugs
Computer Controlled Switching Logic (Input)
Analog to Digital and Ditital to Analog Converters as Required
Small General Purpose Digital Computer
8K Memory Expandible
Digital Tape Recorder - Reproducer
Keyboard Printer
(Not ASR etc)
(10 key keyboard)
Computer Controlled Switching Logic (output)
Numerical Display
Conversion Electronics
Environmental Sensors
①
Control
Control
Control
Controlled AIR OUT
Programmable D.C. Power Supplies (as required)
Environmental Switching Control Logic
Switching Valves etc. for Temperature Control
Heater and LN_2 Control
③
Test Set Power and Device Control Panel
Special Shop Connection for Module Testing
⑥

NOTES:
6. System provides expansion capabilities for system modifications
5. All Computer peripherals include device subcontrollers
4. Includes necessary input/output channels
3. This includes connection for missile inertial unit mounted on furnished gimbaled table
2. Need depends on personnel training level
1. A special interconnect cable to substitute for system to be tested will permit a total test set diagnostic.

Figure 16. Equipment Operating Procedure

GME TEST PROCEDURE Date____________

Before Going to Ramp

1. Check Test Set for: Initial

Valid calibration date ☐

Valid maintenance date ☐

Overall condition ☐

Correct supply of accessories ☐

2. Obtain Tapes (cartridges) for:

All required ramp test programs ☐

Valid mission duty tape ☐

3. Determine

A/C number ____________ ☐

Take-off time ____________ ☐

Flying operators name ____________ ☐

Information file on previous test and/or maintenance ☐

After arrival at A/C before Missile Install

4. Interconnection (Cables)

All main switches OFF
(both test equipment and airborne) ☐

Connect Aux Power unit ☐

Connect cables to A/C interconnect boxes ☐

GME TEST PROCEDURE (Continued)

5. Start Up

Start APU (time________________) ☐

Turn Airborne equipment ON (if necessary) ☐

Turn test set ON (allow 30 minutes warm-up) ☐

During this time energize tape deck and printer and visually inspect airborne equipment for unlocked components or visual sign of malfunction (and cleanliness)

6. Testing

Insert test set self test program ☐

Initiate program ☐

Results OK ☐ Proceed

If not (explain what to do)

Insert Program 2 ☐

Initiate ☐

Results OK ☐ Proceed

Note: Last program will double check current level to insure non-hazardous condition for missile installation and properly set equipment switches.

Missile Pre-installation Checkout

INSTALL MISSLE

Insert program y ☐

Initiate y ☐

(Continue)

Log completion time ____________ ☐

Log A/C number ________________ ☐

GME TEST PROCEDURE (Continued)

Insert Mission program ☐

Initiate program ☐

Return Equipment and logs to shop ☐

Signed______________________

APPENDIX III

APPLICATIONS TO THE DESIGN PROCESS OF THE QUEUING TECHNIQUE FOR DETERMINING SYSTEM MANNING REQUIREMENTS

At the start of the study it was planned to test the utility of the queuing model method of predicting manpower requirements in system design. Barton et al. (1964) indicated as a consequence of their study that "subsystem design engineering may be directed to estimate manning requirements using the manning prediction technique proposed in this report" (section 5.4, p. 97). Manning prediction techniques used in the military services are still largely intuitive; any formalized mathematical prediction method which could be applied to system design would therefore produce significant benefits to that design, provided, of course, that the recommended method was compatible with the manner in which systems were developed.

The queuing technique is too lengthy to describe in detail in this Appendix. Generally, however, the technique requires the analysis of the various parameters which enter into the determination of operational readiness. These parameters include:

(1) Productive time spent in maintenance;
(2) Non-productive time spent in maintenance;
(3) Identification of system functions with task responsibility;
(4) Shift schedules;
(5) Operational performance requirements;
(6) Skill workload (ie, number of personnel of given skill levels per job);
(7) Operational performance readiness, including maintenance requirements;
(8) Reliability requirements, including down time.

Since number of personnel and skill are essential inputs to operational readiness, optimal manning requirements can be determined by varying the readiness requirement and determining the manning needed to support that readiness requirement.

It is necessary to point out that the test of the queuing technique projected for this study was not a test of its validity. Such a test has already been performed by Purvis et al. (1965). Moreover, validation of the queuing technique requires comparison of the operational readiness level predicted by the model and based on a specified manning level, with measured readiness actually achieved by the system in the field. Since the present study involved only the simulation of the conceptual design effort for a maintenance subsystem, no operational system was available as a standard against which to measure technique validity.

However, since our engineering subjects were asked to specify the manpower required to exercise the systems they had designed, it appeared feasible in planning the study to compare these manpower predictions with those produced by implementing the queuing model. If the subjects' predictions did not differ significantly from those produced by the model, one could infer that the design engineer, given merely the appropriate data, could develop manpower predictions essentially equivalent to those produced by the model. The latter would then not be a significant improvement over present methods of predicting manpower. Such a conclusion would not invalidate the model, but would merely suggest that engineers, when given the raw data inputs used in the model, could integrate those data subjectively with the same degree of efficiency as does the model. On the other hand, if there were a significant discrepancy between model and subject estimates, and if the model estimates corresponded with the manpower provided for the operational subsystem used as the basis for the design requirements in this study, the utility of the model as a predictive device would be enhanced.

As it turned out, it was not feasible to compare queuing model predictions with manpower predictions made by subject engineers because of the security classification required for the data inputs. To exercise the model would have required data on the actual operational reliability and availability of the B-52 aircraft and the predicted reliability and availability of the AGM-69A. The parameters for which information was required were:

(1) Arrival rate of missiles to be maintained in the shop (somewhat analogous to failure rate);

(2) Number of B-52 aircraft in the smallest organizational element to be serviced by the shop (eg, wing, squadron);

(3) Number of B-52 flights per day;

(4) Amount of work time available in the shop;

(5) Amount of time required to check out the electronics subsystems in the missile and in the CAE brought to the shop for fault diagnosis;

(6) Number of spares available for missile and CAE components;

(7) Operational readiness requirements of the smallest organizational element serviced by the shop.

In addition, our engineering subjects made their manpower predictions based on only a few of the parameters required by the model (eg, system functions, operational performance requirements, skill workload and reliability requirements). Even when the designer utilized the same parameters, the information describing these parameters was at a much grosser level than that presumably available to the user of the queuing technique. For example, the engineer had the reliability requirement available to him, but this was not broken down by the actual or allowable down time. Hence, any comparison between the predictions made from the two sources would in any event have been faulty. For all these reasons the analysis originally contemplated was discarded.

It was, however, possible to ask the question; what are the problems involved in having design engineers use the model in the course of early system development? Specifically,

(1) What kind of input information does the design engineer need to make early manpower predictions?

(2) How should that information be presented to him?

(3) Can/will the design engineer use the information supplied by the queuing model to influence his design?

In answering the first question it is necessary to review the informational inputs ordinarily provided to the engineer during development. This was ascertained by asking the engineer, whenever an item of information was given him, whether he ordinarily received that information during system development.

It is apparent from results of the present study that only a few of the informational inputs required by the queuing model are ordinarily available to the design engineer. Certainly none of the data items referred to earlier as being necessary inputs are ordinarily available to him. When the subject engineers were asked whether they ordinarily received inputs such as those provided in the SOW, about half of them responded negatively. Queuing models inputs would be even less available to them.

From this standpoint it would be a reasonable hypothesis that the queuing manpower prediction would be more exact and hence more valid than the engineer's subjective prediction, if only because the former is based on many more informational inputs.

There may be two possible reasons why the design engineer does not receive all the informational inputs required by the model. First, the information may not be available at an early enough stage in system development for the engineer to make use of it. We have pointed out elsewhere (Meister et al., 1968) that the human factors analyses required by AFSC 375-5 are not ordinarily performed at the time for which they are specified. This is corroborated by the fact that design engineers report that they do not ordinarily receive the results of such analyses.

Second, it may be that even where the model outputs are available early enough, they are not provided to the design engineer because they are assumed not to have any design value for him.

With regard to this second hypothesis, the results of the present study suggest that manpower predictions made by exercising the model would significantly influence design if these predictions were formulated as design requirements (ie, requirements to which the engineer must design).

Information which is not or cannot be interpreted as a design requirement is generally ignored by the design engineer. Thus, raw data inputs to the queuing model (eg, shift schedules) would probably be received by the engineer as largely irrelevant unless design requirements were implicit in these data. On the other hand, he pays great attention to information which is clearly labelled as a requirement. If a manpower prediction is presented to him as a desirable goal, or even as a likely to be accomplished goal, it has no impact on the engineer's design. However, if the prediction specifies that equipment will be designed to a maximum of N personnel, it does have a significant effect on his design conceptualizations. The results of previous studies suggest that engineers can modify their design in accordance with the number of personnel required to operate and maintain that design. The same is true, within more restricted limits, for different levels of skill.

The point is that the queuing model manpower predictions must be formulated to the engineer as a design requirement rather than either as raw data inputs, a prediction or as "nice to know" information. Consequently the queuing model will be useful in design only if the analysis is performed prior to the time the RFP is issued and if the model predictions are incorporated in the RFP as design requirements, eg, the equipment will be designed so that no more than a maximum number of personnel with designated skill levels will be required to service the equipment.

It should be pointed out that any requirements presented to the design engineer must be formulated in terms of the individual major equipments which he is designing. Thus, the requirement must be in terms of N personnel to maintain X equipment. This may present a problem to the queuing model because its outputs are phrased in terms of number of repair channels required by the supported system. This may pose a difficulty when one wishes to determine the manning requirement within a single channel, such as a specific ground support equipment or test set. The requirement must be broken down to number of personnel of required skill levels performing specific tasks on specific equipment.

The technique does, however, predict the total number of personnel for the individual squadron or wing. If one knows the number of equipments required for the squadron or wing, it should be possible to allocate manpower per equipment unit.

As a corollary to the concept of providing the designer with the manpower prediction as a requirement early in system development, it follows that he cannot personally be expected to perform the model analyses needed to derive the manpower prediction. While it is relatively simple for him to make an intuitive manpower prediction based on the relatively few inputs he ordinarily uses, it would be grotesque to expect the design engineer to perform the sophisticated mathematical computations inherent in the model, if only because he would not have the time needed. This is especially so, since, for the manpower prediction to have maximum design consequences, it should be provided by the customer in the RFP. The model analyses and the tradeoffs should therefore be performed by operations researchers preferably in the Air Force and then its outputs should be transmitted to the engineer as a design requirement.

The two major components of the manpower prediction are personnel number and skill level. The engineer finds it easier to design to the quantity than to the skill level requirement. The reason is that number is a very simple concept, whereas skill is, as we have seen, a composite of many parameters. The Air Force's 3, 5, 7 level categorization of skill is almost uninterpretable by the engineer in terms of quantity of skill, much less the consequences of that skill. Moreover, we know little about the relationship between quantity of skill and individual design characteristics. From that standpoint the queuing model manning prediction can be used for design primarily in terms of its personnel quantity rather than its skill level parameters. This is not a limitation specifically of the queuing model but of the design capability inherent in the manpower parameters.

The model manpower predictions, if specified as requirements, will permit design tradeoffs. For example, if the queuing technique suggests two possible alternatives, eg, 2 or 4 men, then the engineer can analyze the design consequences of these two alternatives and select the more desirable. Any such alternatives must be phrased in terms of whole individuals, eg, 1, 2, 3 men, and the alternatives presented to the designer should represent extremes of the range of alternatives.

The engineer cannot, however, be expected to make formal mathematical analyses in these tradeoff problems, because a formal mathematical method of combining various design tradeoff parameters (eg, reliability, maintainability, cost) does not exist.

The queuing model technique may also be used as a "after the design fact" method. Once design has been accomplished and a manning level specified, the actual operational readiness for the system can be secured. If that operational readiness does not satisfy system requirements, it will be of interest to determine whether system manning can be modified to improve operational readiness. The analysis of the queuing model is performed in reverse: knowing the operational readiness achieved, one analyzes for the parameters (among them manpower) influencing that readiness. Changes in readiness might then be secured by modifying manning skill levels. However, it must be remembered that manpower is in part dependent on system design, and where design is fixed, as it would be in an operational system, changes following development of the hardware are not easy to achieve.

In summary, then, one can say the following:

(1) The queuing model can be useful to design if the necessary analyses are performed quite early in system development (by the time the RFP/SOW is issued) and if the results are presented as design requirements, not as information. (This statement is true of any manpower prediction, from whatever source.)

(2) To be maximally useful, manpower predictions should be formulated in terms of the number/skills of personnel needed per unit to be designed.

(3) The personnel quantity component of the manpower prediction is more easily utilized by the engineer than is the skill component.

(4) The mathematical analyses required to make the queuing model predictions must be performed by someone other than the design engineer.

(5) The queuing technique may also be used in an "after the design fact" evaluation of achieved operational readiness levels, but is less valuable in this way because of the difficulty of achieving design changes following hardware development.

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